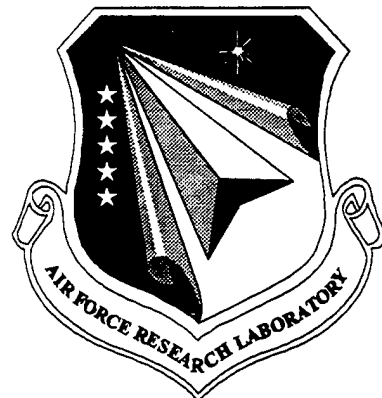


AFRL-VA-WP-TR-1998-3004

**ANALYSIS OF LIMIT CYCLE
OSCILLATION/TRANSONIC HIGH
ALPHA FLOW VISUALIZATION**



Part 2: Stationary Model Data

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13. ABSTRACT (Maximum 200 words) A flow visualization test was conducted with the simple straked wing in August, 1996 (at the National Aerospace Laboratory [NLR], The Netherlands), for the purpose of obtaining flow visualization data to complement the pressure and force data base generated in earlier tests of the same configuration. This test was conducted in two parts to examine the flow field characteristics (1) at high alpha conditions that involve vortices, shocks, and separated flows, and (2) at low alpha conditions typical of transonic LCO flows with and without tip stores. Laser light sheet/water vapor techniques were used to illuminate the flows, and video recording was used to obtain the data. Both low and high speed video cameras were used to examine spanwise and streamwise laser sheet positions. In addition, under NLR funding, some preliminary particle image velocimetry (PIV) data were obtained at M=0.225 and 0.6, as well as some pulsed laser flow visualization (9 nano-sec pulse) at M=0.9. Correlation was performed between the flow visualization data from this test and the pressure/force data obtained in 1992 on the same configuration. This report contains the flow visualization results for the stationary model.				
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FOREWORD

This report summarizes the results of an investigation into transonic unsteady aerodynamics. Transonic wind tunnel tests were conducted for a semispan straked delta wing model with and without tip stores. Laser light sheet and water vapor were used to obtain flow visualization data to complement force and pressure data obtained in a previous test with the same model.

This test was conducted under a cooperative program of research between the Lockheed Martin Tactical Aircraft Systems (LMTAS), Fort Worth, Texas, USA and the National Aerospace Laboratory (NLR), Amsterdam, The Netherlands. The test was conducted in August, 1996 at NLR. The model and support system were designed and fabricated at NLR under an earlier subcontract during 1989 to 1993 from LMTAS (previously the Fort Worth Division of General Dynamics) that was funded under Air Force Contract F33657-84-C-0247 (CCP4551) for the Aeronautical Systems Center, Wright Patterson Air Force Base, Ohio. Additional funding was also provided for this earlier effort by NLR and the Dutch Ministry of Defense. The August, 1996 flow visualization test preparation, wind tunnel test, and reporting were performed at NLR under a follow-on subcontract from LMTAS. This work was conducted under Air Force Contract F49620-94-C-0093, Air Force Office of Scientific Research, Bolling Air Force Base, DC and administered by Dr. Leonidas Sakell, AFOSR/NA. Funding was provided by the Wright Laboratory Flight Dynamics Directorate, Wright Patterson Air Force Base, Ohio and administered by Mr. L. J. Huttshell (AFRL/VASV). Additional funding was provided by NLR. With funding provided by the Dutch Ministry of Defense, the test was extended with additional measurements on the tip launcher and tip missile configurations. This funding was monitored by Mr. C. Hoffman and Mr. E. Bos of The Netherlands Agency for Aerospace Programmes (NIVR-Contract: 07501N).

The Program Manager was Dr. A. M. Cunningham, Jr. at LMTAS. The principal investigators were Dr. Cunningham at LMTAS, Mr. E. G. M. Geurts at NLR, and Mr. R. G. den Boer (during the early part of the program) also at NLR. Assistance was provided by the following NLR specialists, C.D.G. Dogger, A. J. Persoon, and R. J. Zwaan.

This test is documented in three parts. Part 1 (AFRL-VA-WP-TR-1998-3003) presents background, test setup, and data base descriptions. A detailed discussion of results is also given with continuous references to the data presented in Parts 2 and 3, AFRL-VA-WP-TR-1998-3004 and AFRL-VA-WP-TR-1998-3005. This report (Part 2) includes a large selection of flow visualization video frames and accompanying pressure data for the model stationary at varying Mach and incidence. Part 3 is similar to Part 2, but is for the model oscillating in pitch at both small and large amplitudes also for varying Mach and incidence. The three parts are listed below:

1. "Analysis of Limit Cycle Oscillation/Transonic High Alpha Flow Visualization, Part 1: Discussion", AFRL-VA-WP-TR-1998-3003.
2. "Analysis of Limit Cycle Oscillation/Transonic High Alpha Flow Visualization, Part 2: Stationary Model Data", AFRL-VA-WP-TR-1998-3004.
3. "Analysis of Limit Cycle Oscillation/Transonic High Alpha Flow Visualization, Part 3: Oscillating Model Data", AFRL-VA-WP-TR-1998-3005.

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1.0 HIGH SPEED VIDEO FLOW VISUALIZATION AND PRESSURE DATA FOR THE CLEAN WING AT $M = 0.6$, $\alpha = 6$ DEG TO 28 DEG

Individual frames from the high speed video data base (1000 frames per second) on tape are presented in this section for the spanwise sheet position 9 as shown in Figure 1, below. These data are taken from a slow incidence sweep for which the video data were recorded only on VHS tape. The angles chosen for presentation were selected to correspond to pressure data points that are available from Reference 1. Both pressure and flow visualization data are shown in Figures 2.01 through 2.20 in a side-by-side format in order to permit direct correlation.

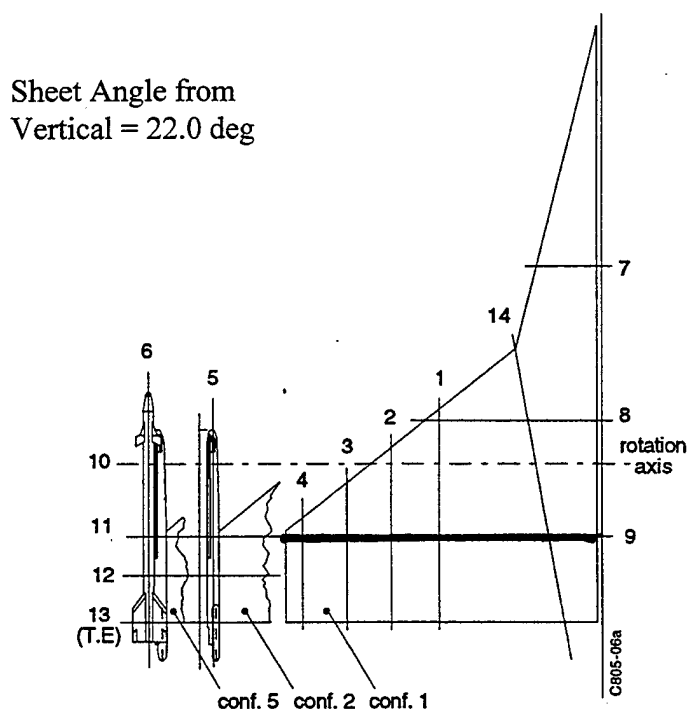
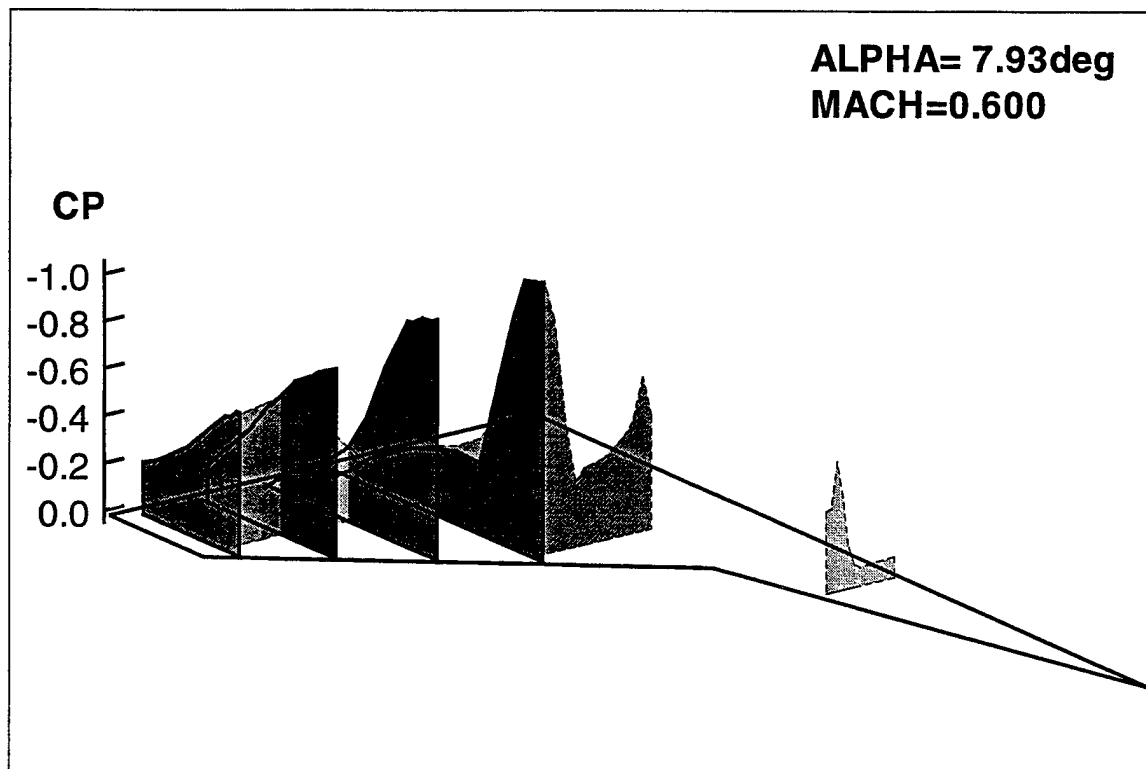
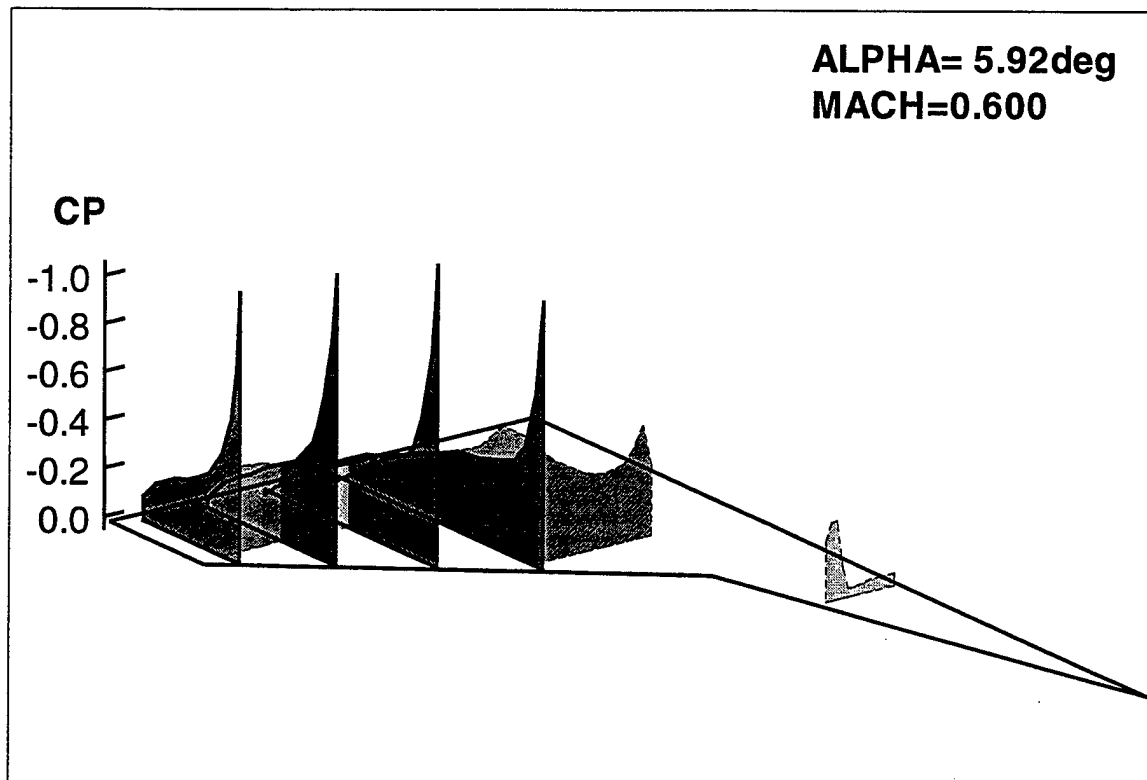
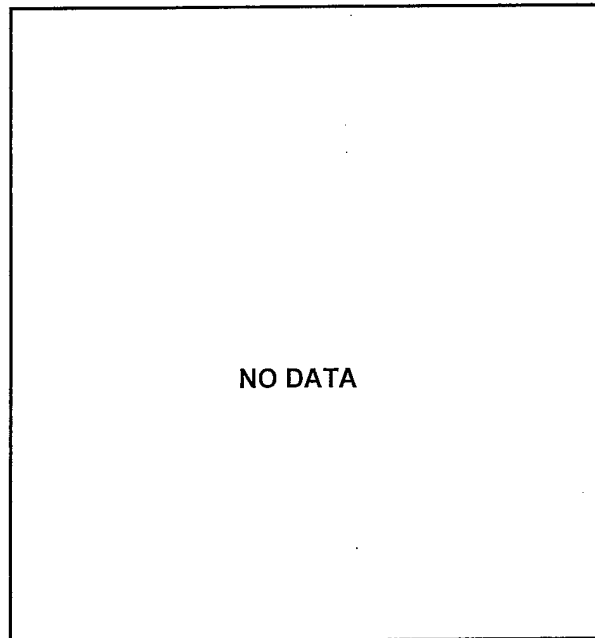


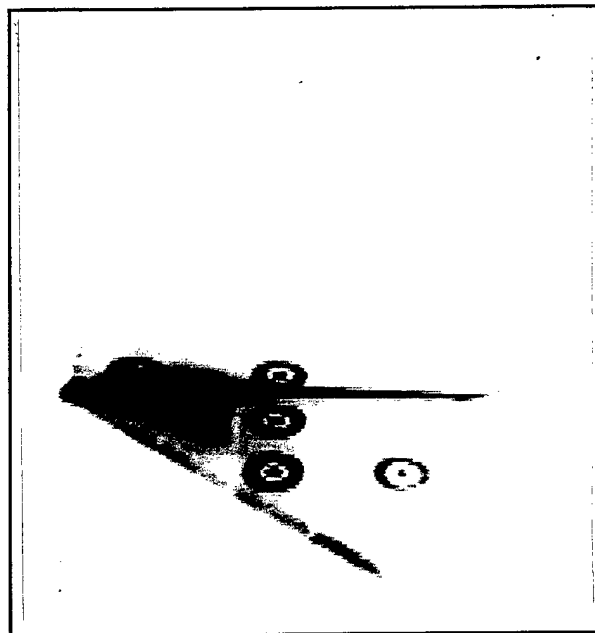
Figure 1 - Flow Visualization Sheet Location for Figures 2, Clean Wing, $M = 0.6$,
 $\alpha = 6$ deg to 28 deg



**Figure 2.01 - Steady Pressure Distributions at
Angles of 5.92 deg and 7.93 deg**

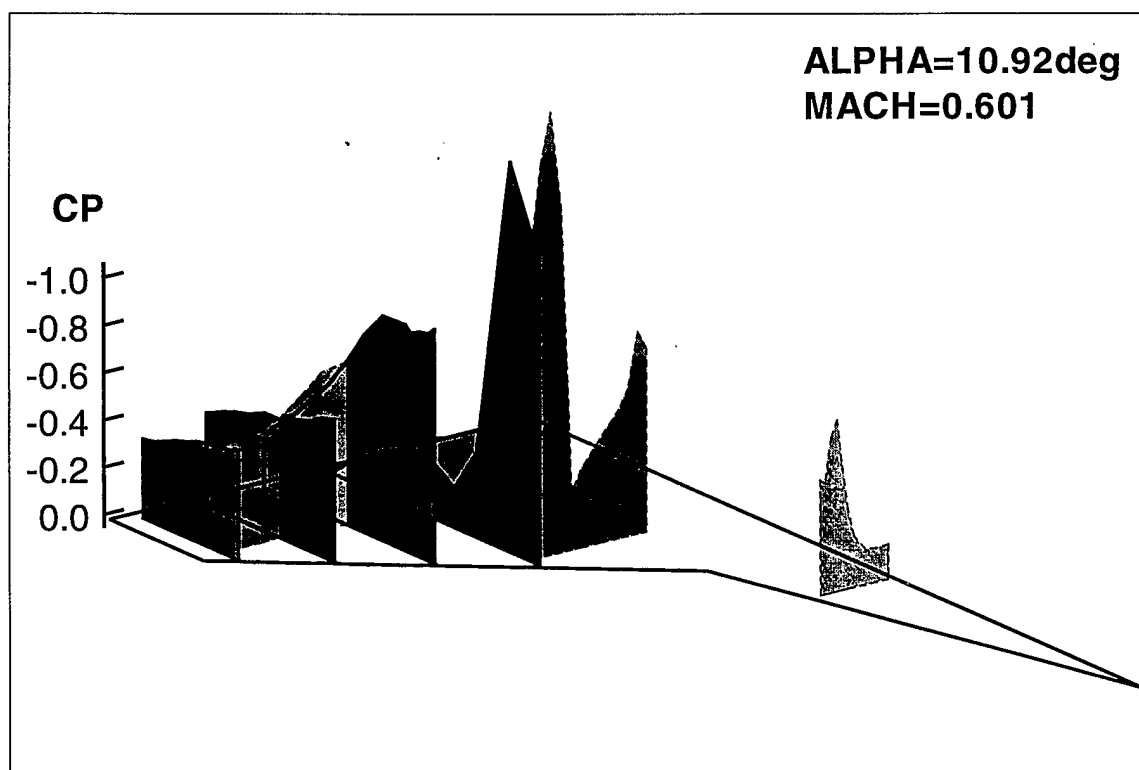
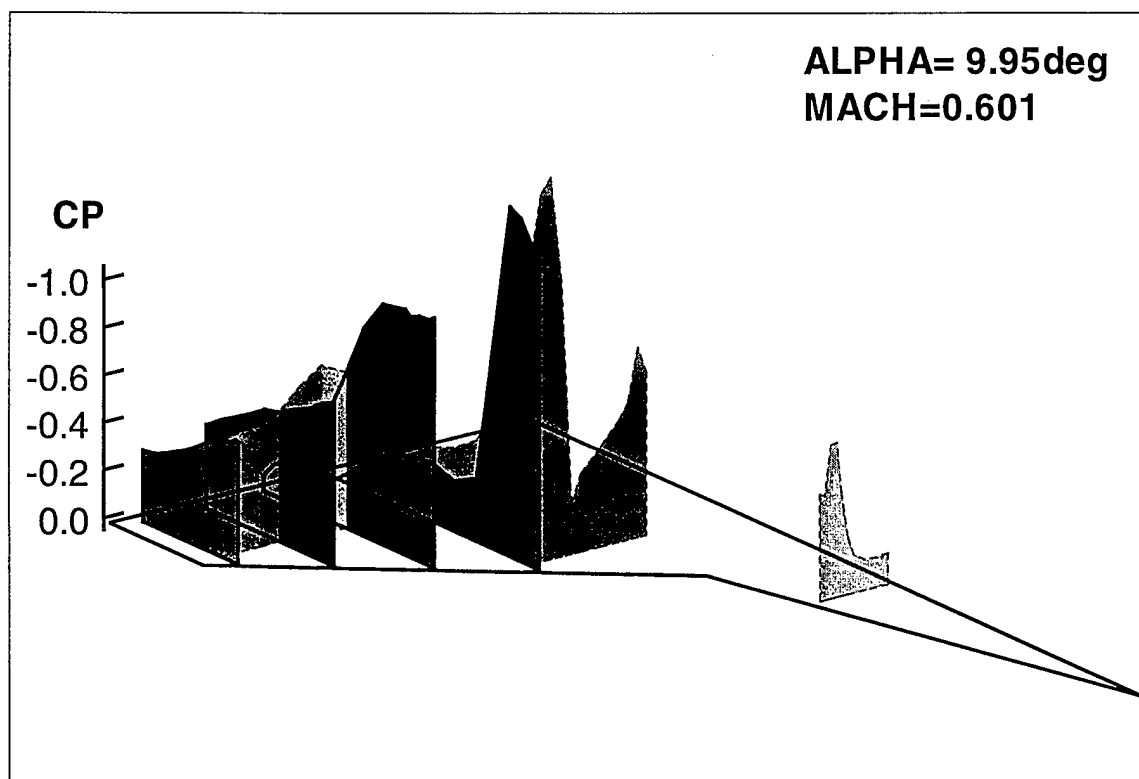


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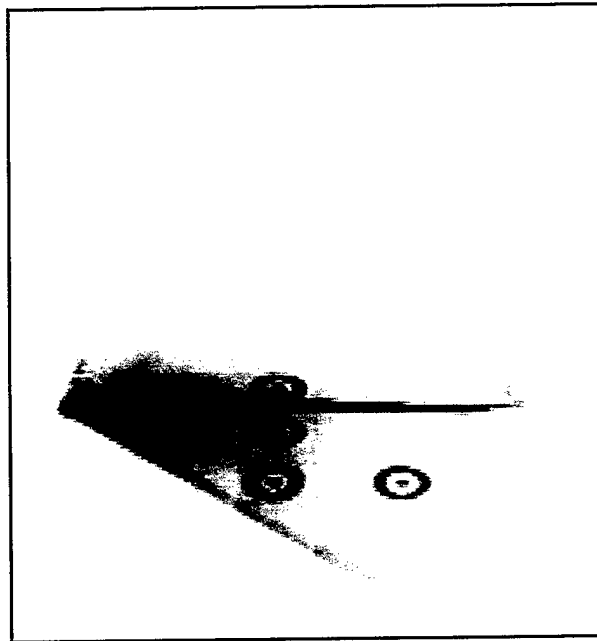


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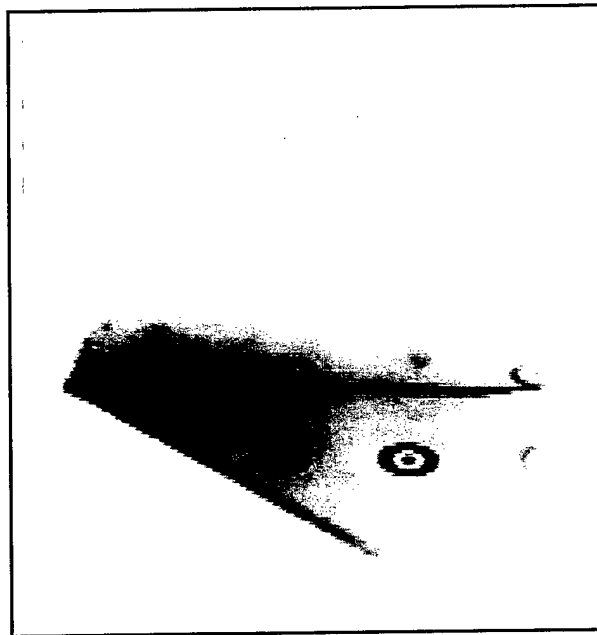
**Figure 2.02 - High Speed Camera View of Spanwise Laser Light
Sheet at $M = 0.6$, Alpha = 6.0 deg and 8.0 deg**



**Figure 2.03 - Steady Pressure Distributions at
Angles of 9.95 deg and 10.92 deg**

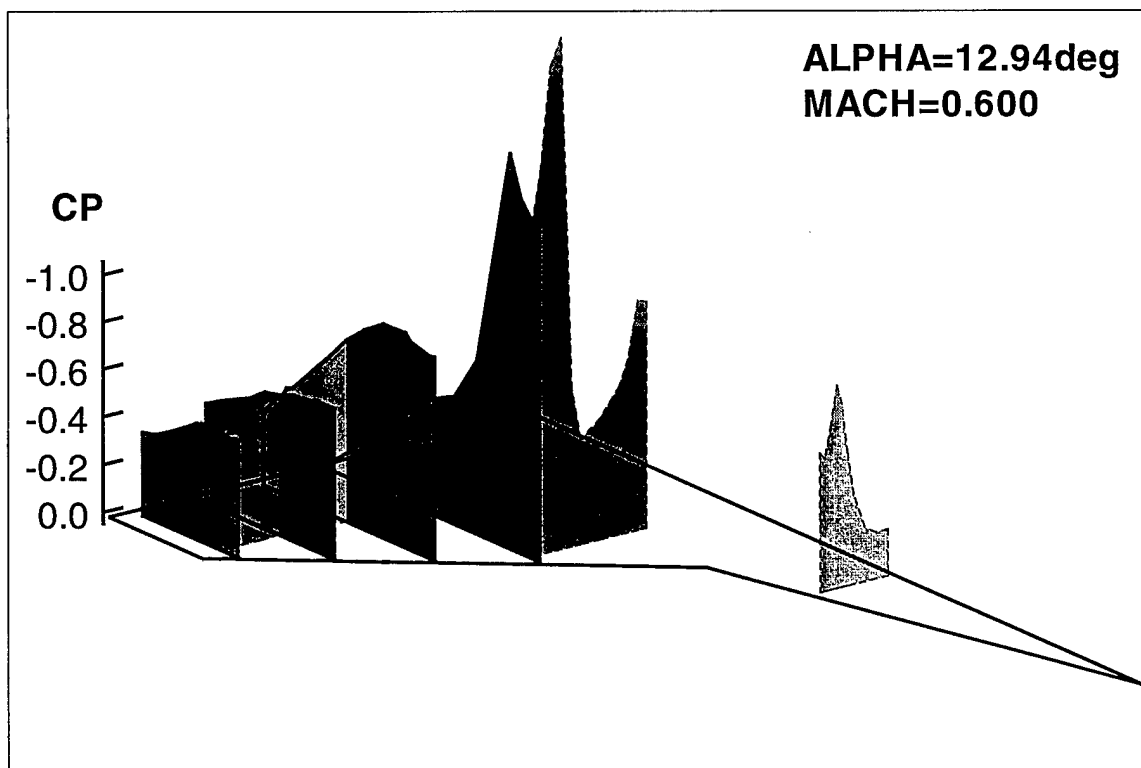
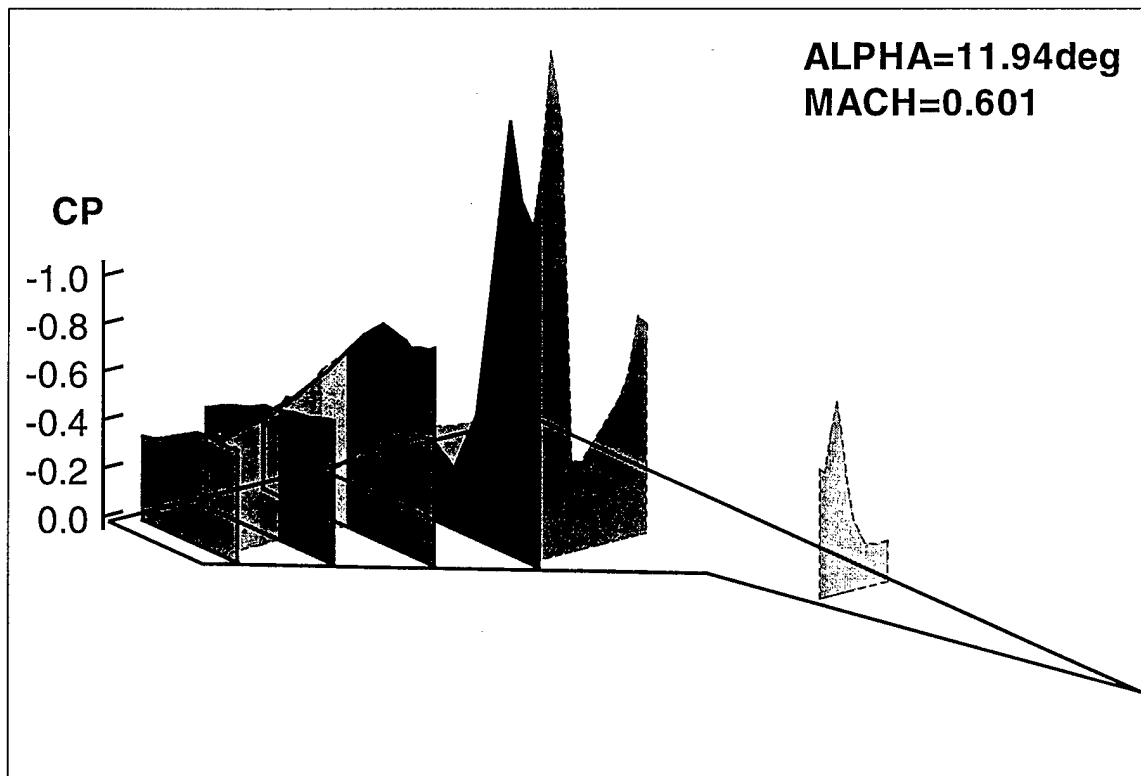


Sheet Position 9, Alpha = 10.0 deg
(Run ID = 79, Frame = -801)

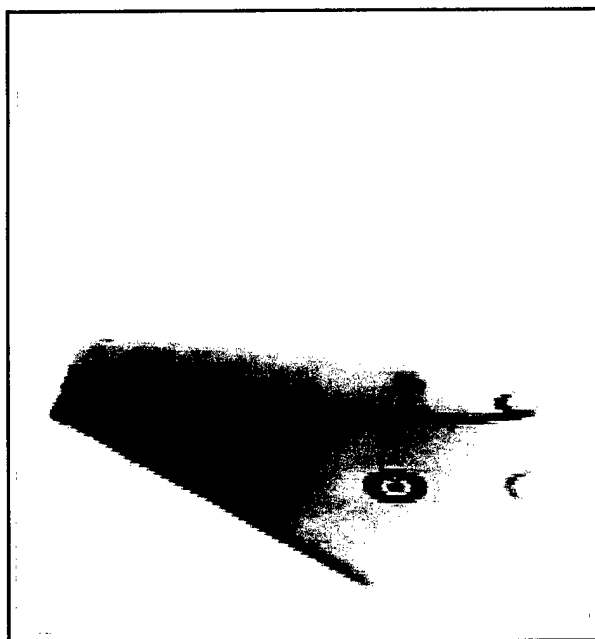


Sheet Position 9, Alpha = 11.0 deg
(Run ID = 79 Frame = -741)

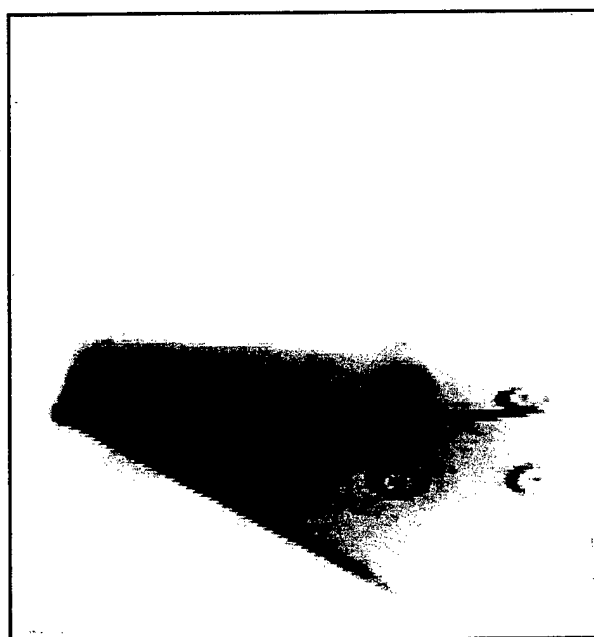
Figure 2.04 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.6$, Alpha = 10.0 deg and 11.0 deg



**Figure 2.05 - Steady Pressure Distributions at
Angles of 11.94 deg and 12.94 deg**

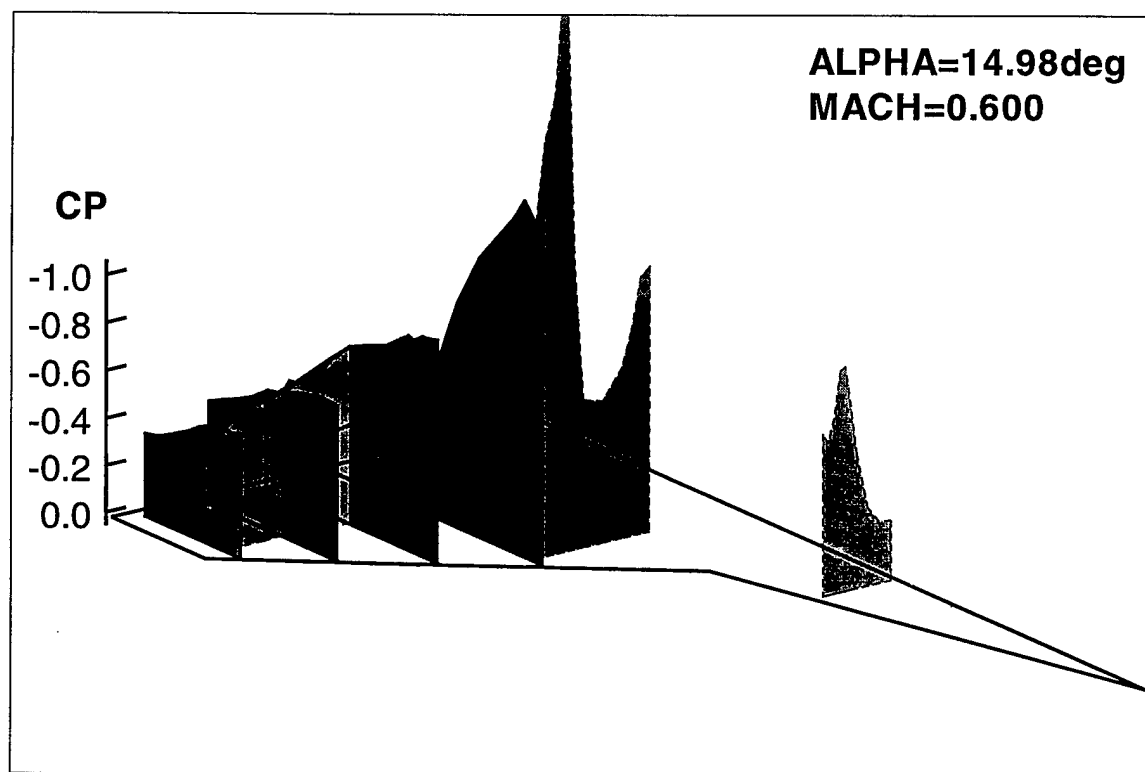
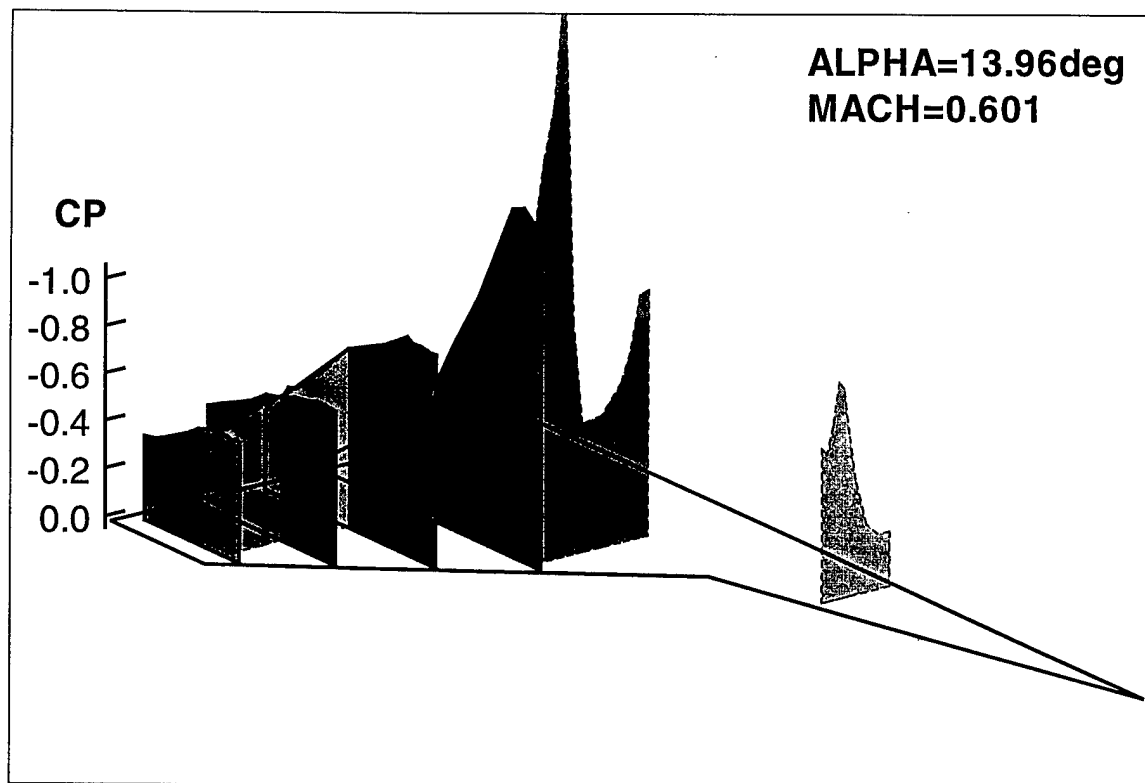


Sheet Position 9, Alpha = 12.0 deg
(Run ID = 79, Frame = -711)

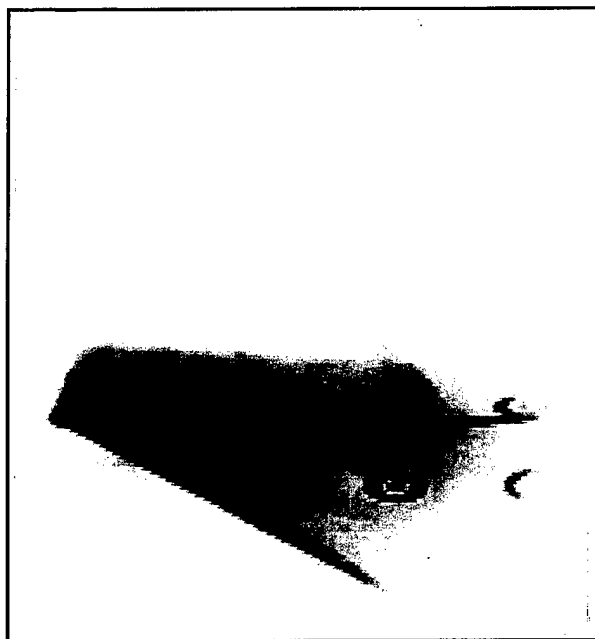


Sheet Position 9, Alpha = 13.0 deg
(Run ID = 79 Frame = -681)

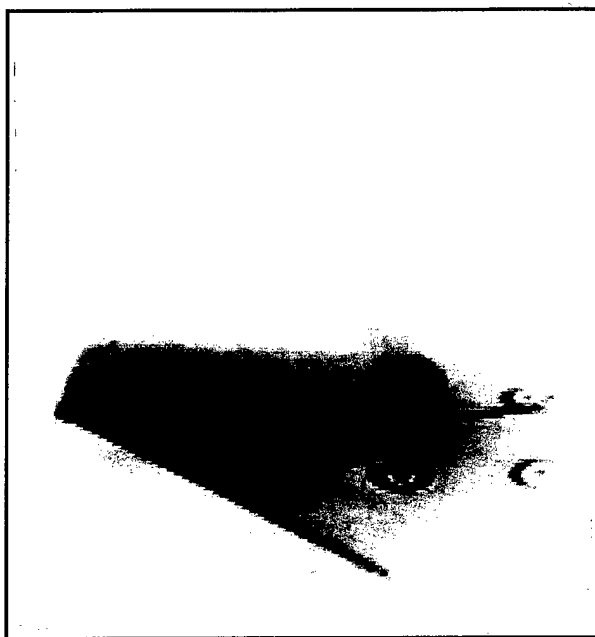
Figure 2.06 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.6$, Alpha = 12.0 deg and 13.0 deg



**Figure 2.07 - Steady Pressure Distributions at
Angles of 13.96 deg and 14.98 deg**

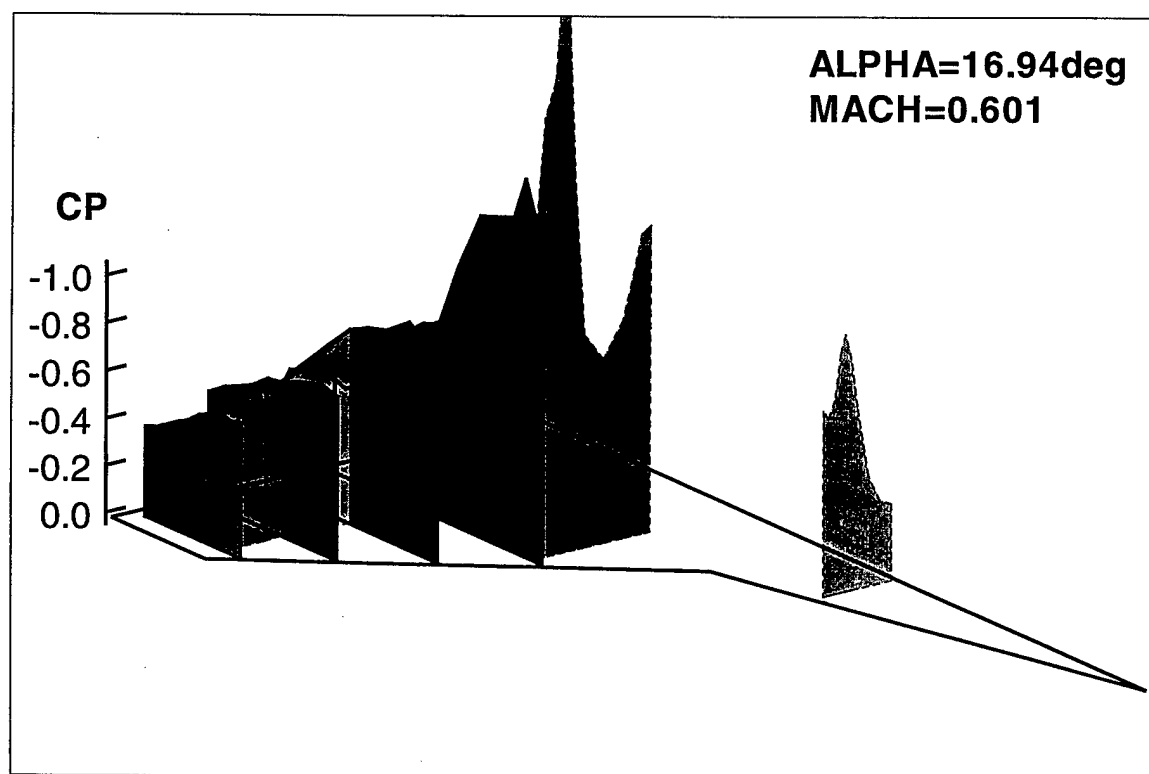
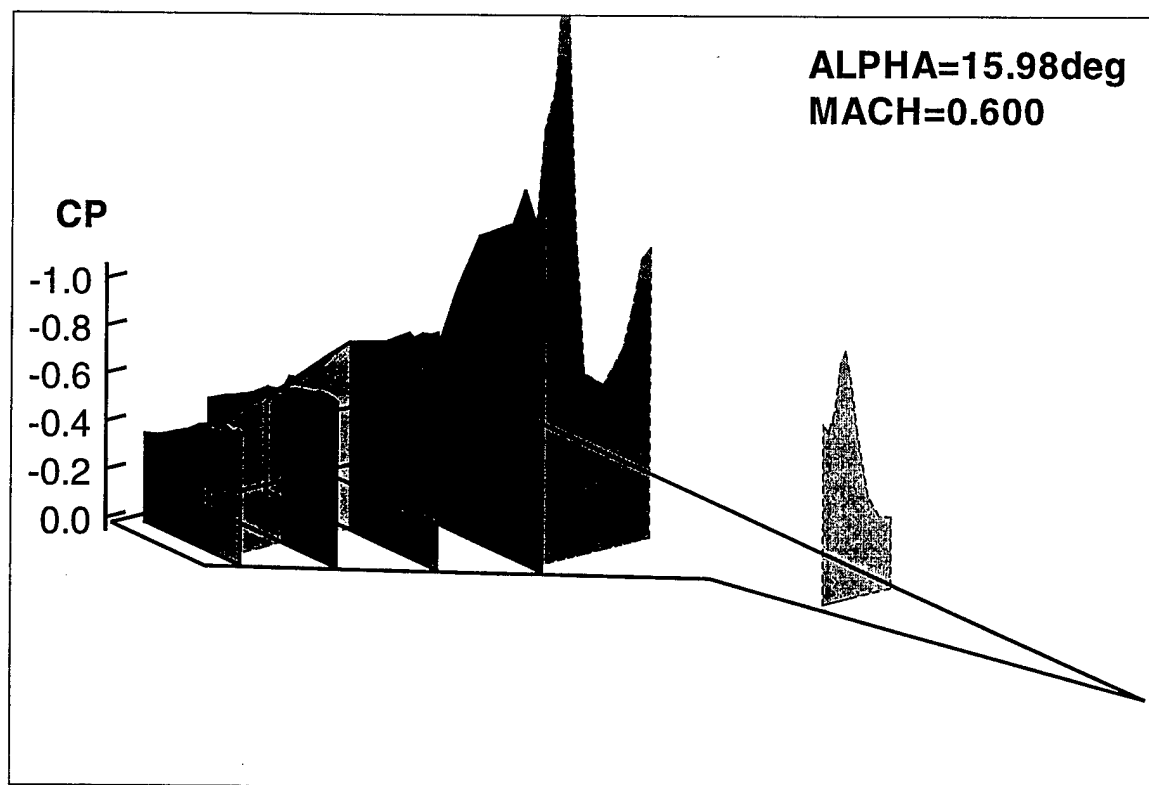


Sheet Position 9, Alpha = 14.0 deg
(Run ID = 79, Frame = -651)

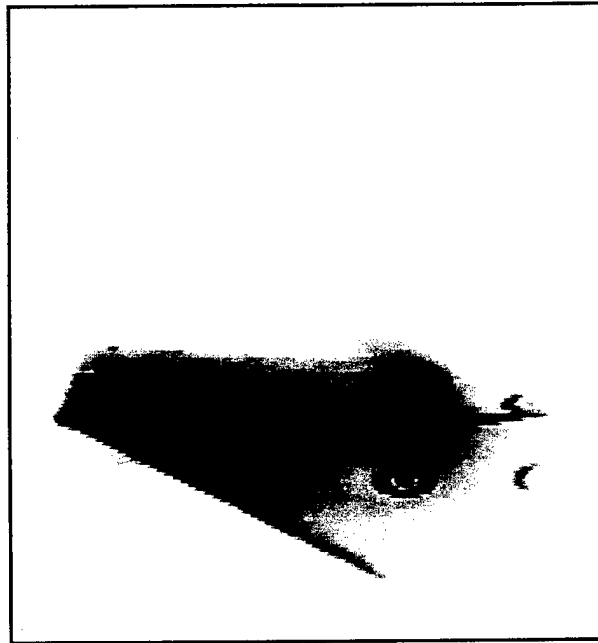


Sheet Position 9, Alpha = 15.0 deg
(Run ID = 79 Frame = -621)

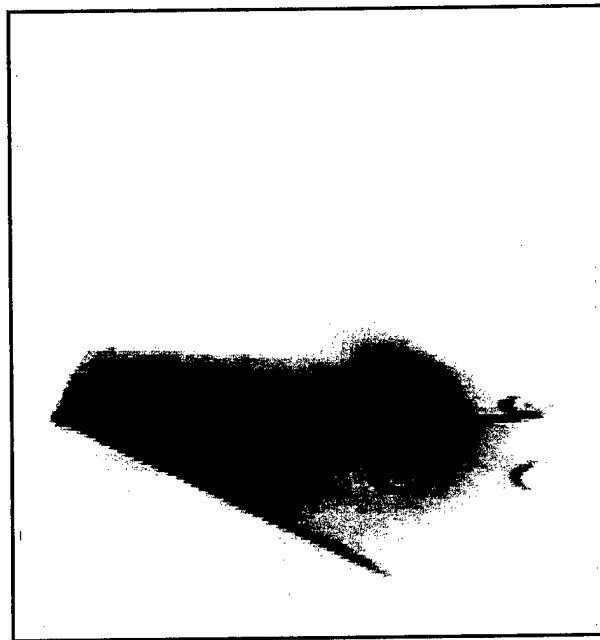
**Figure 2.08 - High Speed Camera View of Spanwise Laser Light
Sheet at $M = 0.6$, Alpha = 14.0 deg and 15.0 deg**



**Figure 2.09 - Steady Pressure Distributions at
Angles of 15.98 deg and 16.94 deg**

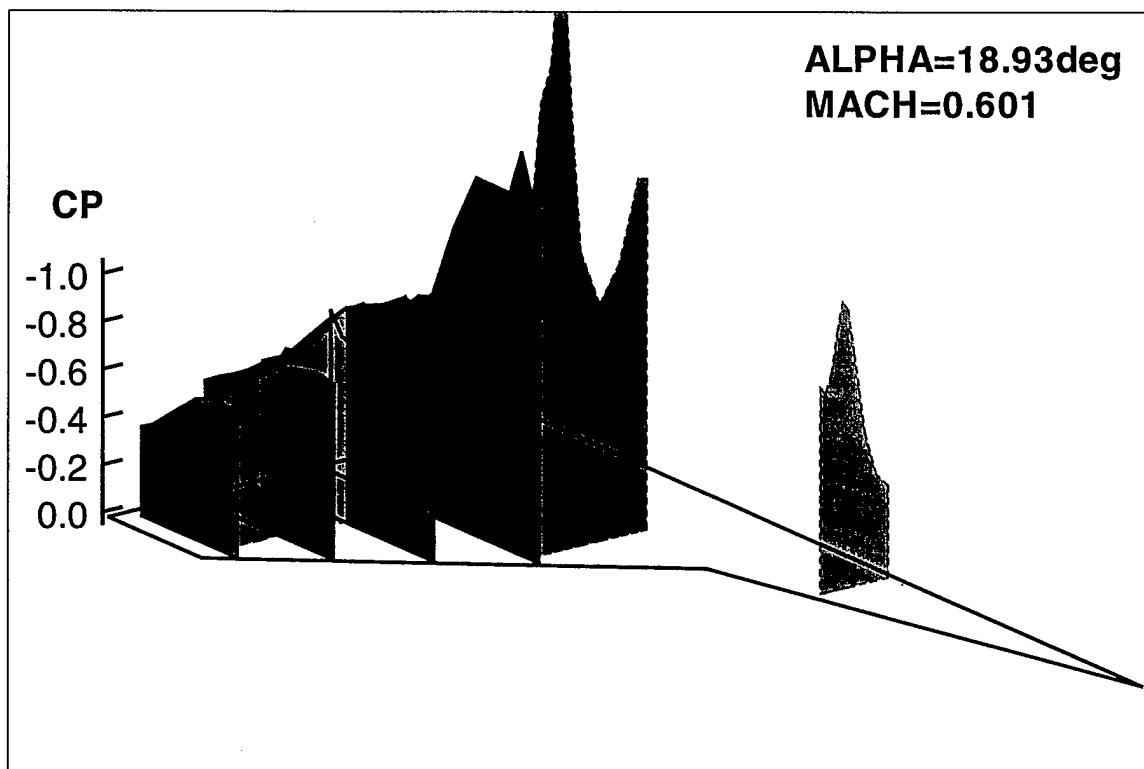
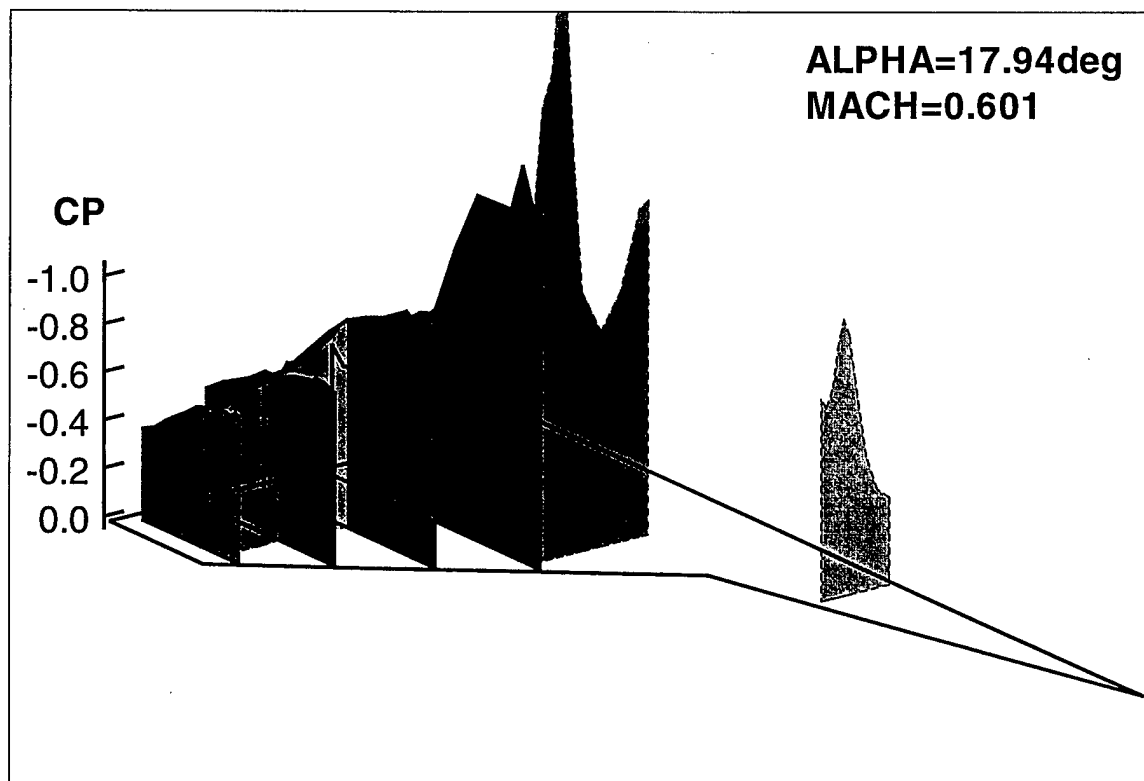


Sheet Position 9, Alpha = 16.0 deg
(Run ID = 79, Frame = -591)

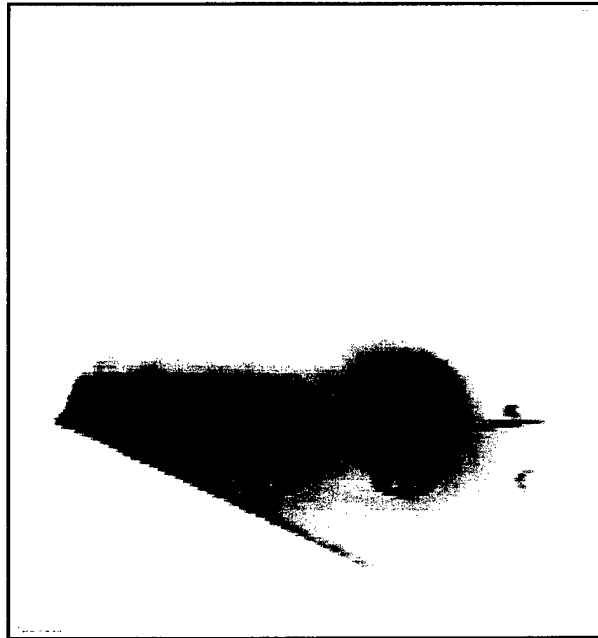


Sheet Position 9, Alpha = 17.0 deg
(Run ID = 79 Frame = -561)

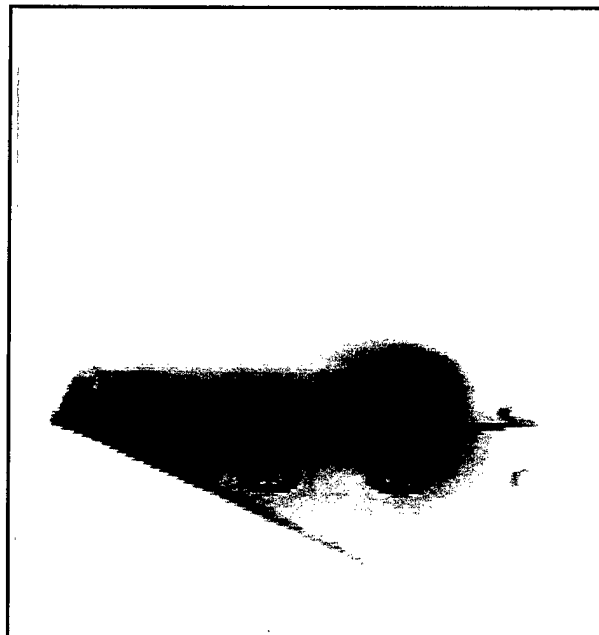
Figure 2.10 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.6$, Alpha = 16.0 deg and 17.0 deg



**Figure 2.11 - Steady Pressure Distributions at
Angles of 17.94 deg and 18.93 deg**

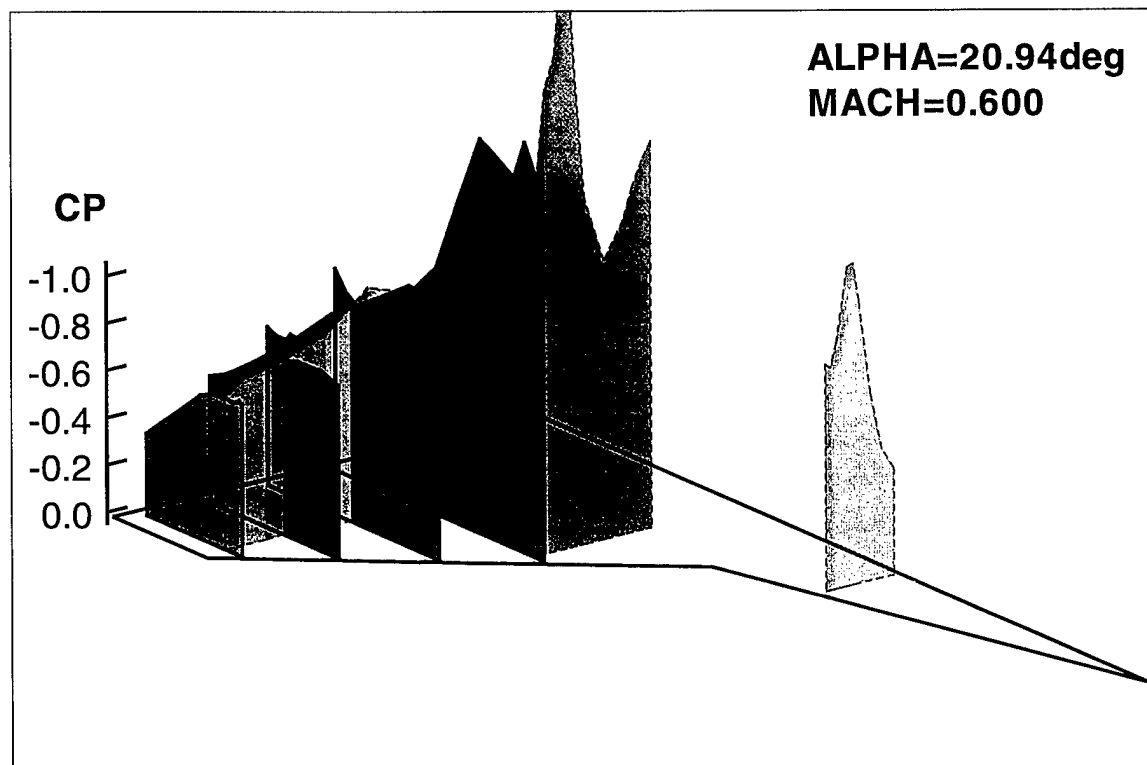
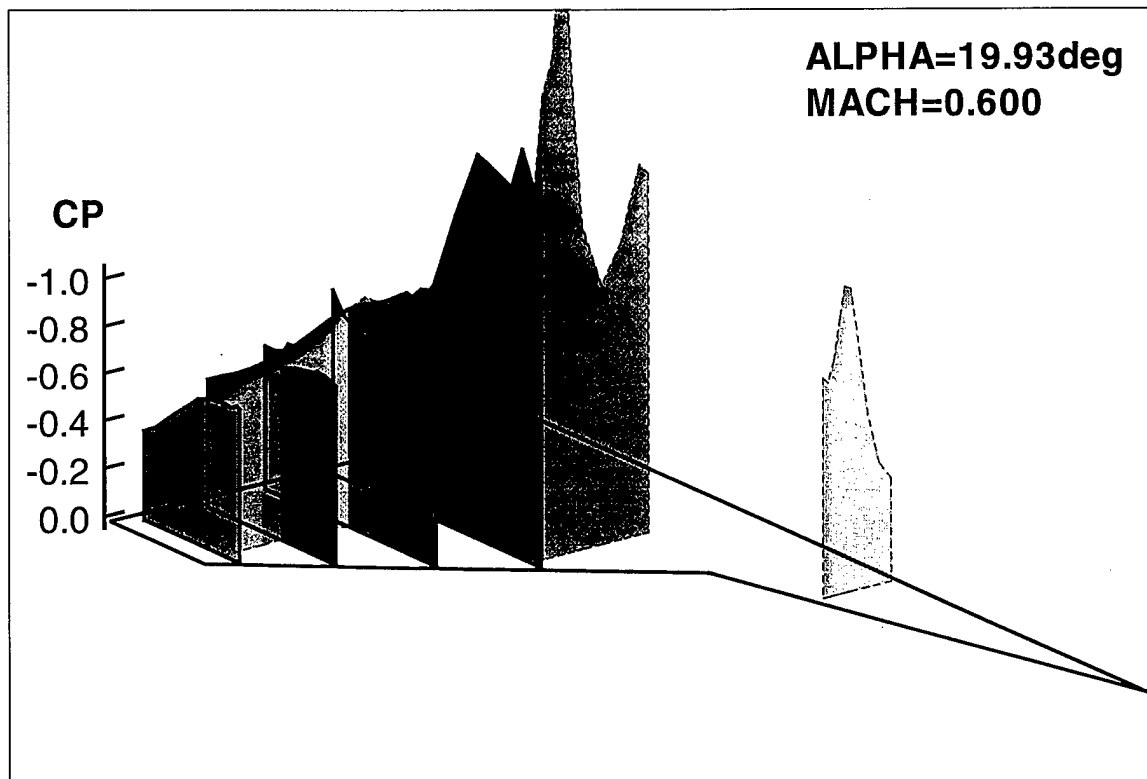


Sheet Position 9, Alpha = 18.0 deg
(Run ID = 79, Frame = -531)

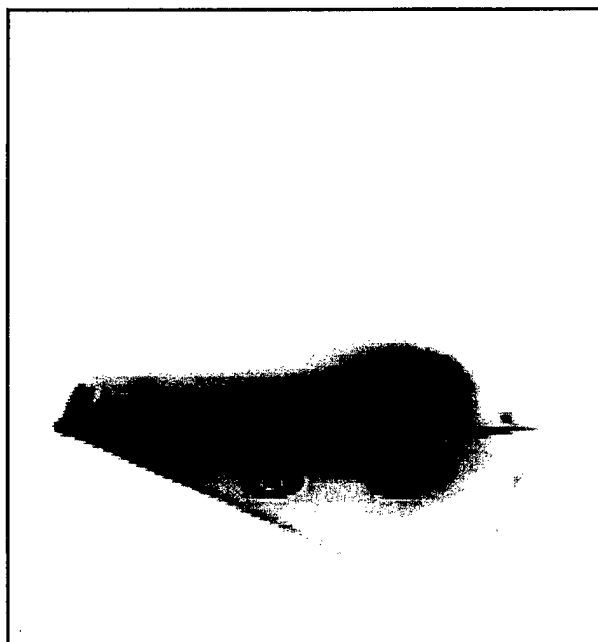


Sheet Position 9, Alpha = 19.0 deg
(Run ID = 79 Frame = -501)

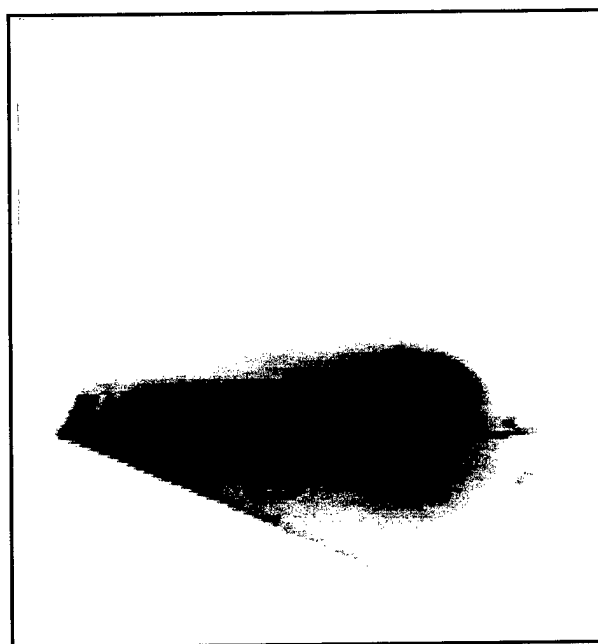
Figure 2.12 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.6$, Alpha = 18.0 deg and 19.0 deg



**Figure 2.13 - Steady Pressure Distributions at
Angles of 19.93 deg and 20.94 deg**

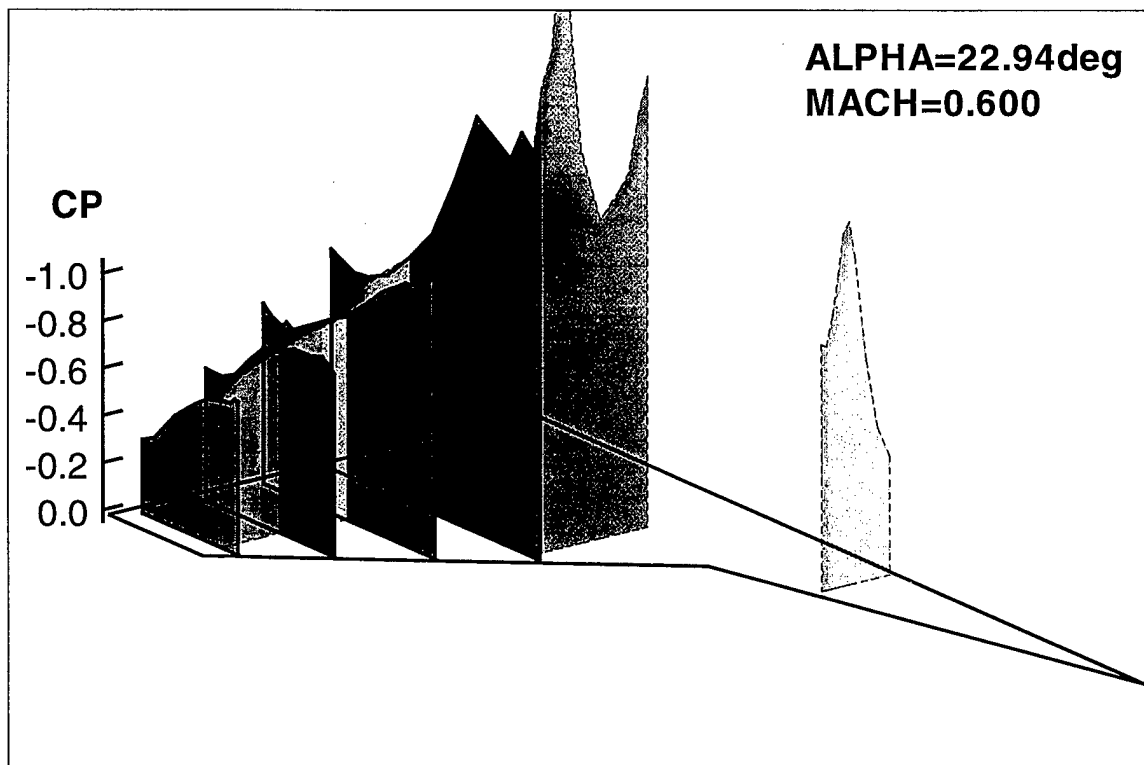
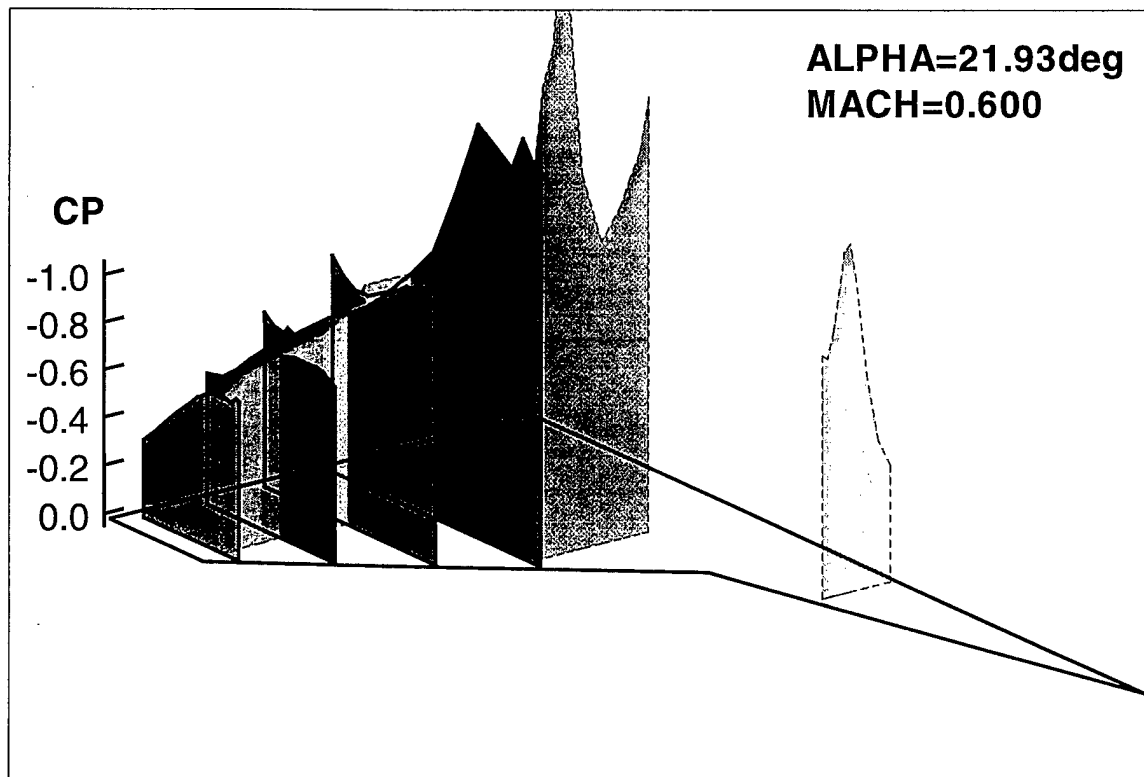


Sheet Position 9, Alpha = 20.0 deg
(Run ID = 79, Frame = -471)

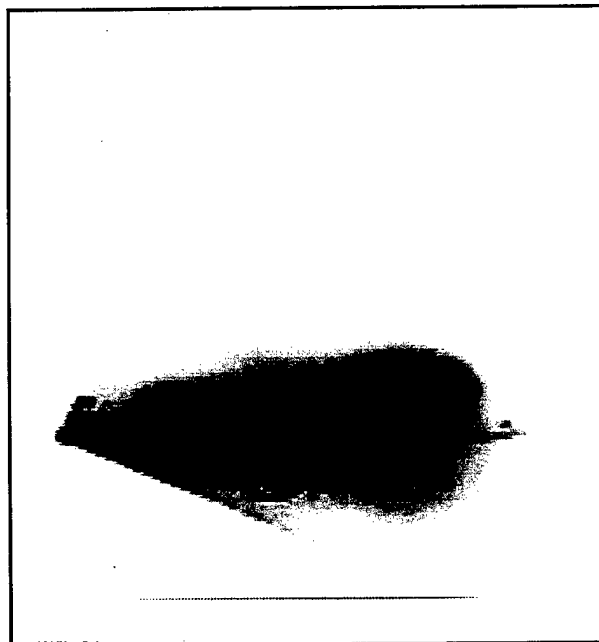


Sheet Position 9, Alpha = 21.2 deg
(Run ID = 79 Frame = -441)

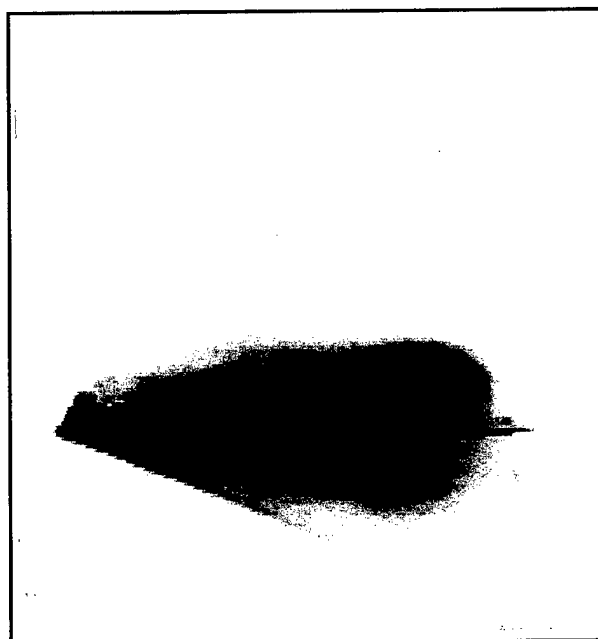
Figure 2.14 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.6$, Alpha = 20.0 deg and 21.2 deg



**Figure 2.15 - Steady Pressure Distributions at
Angles of 21.93 deg and 22.94 deg**

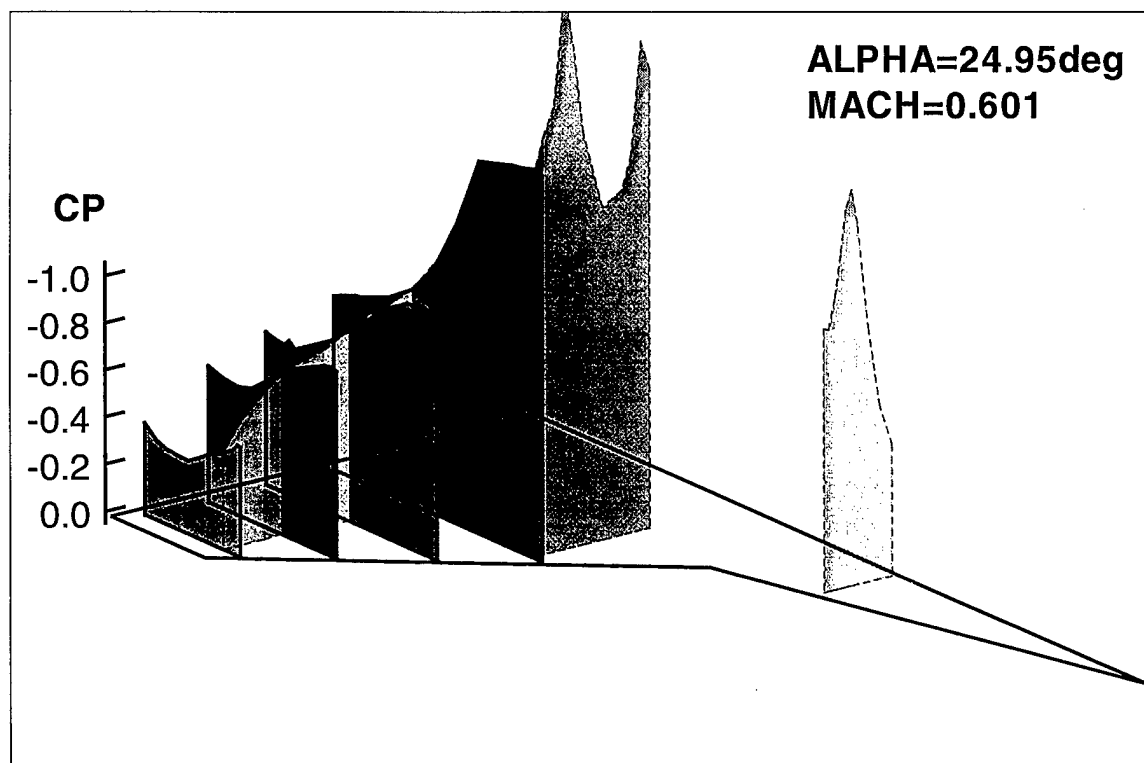
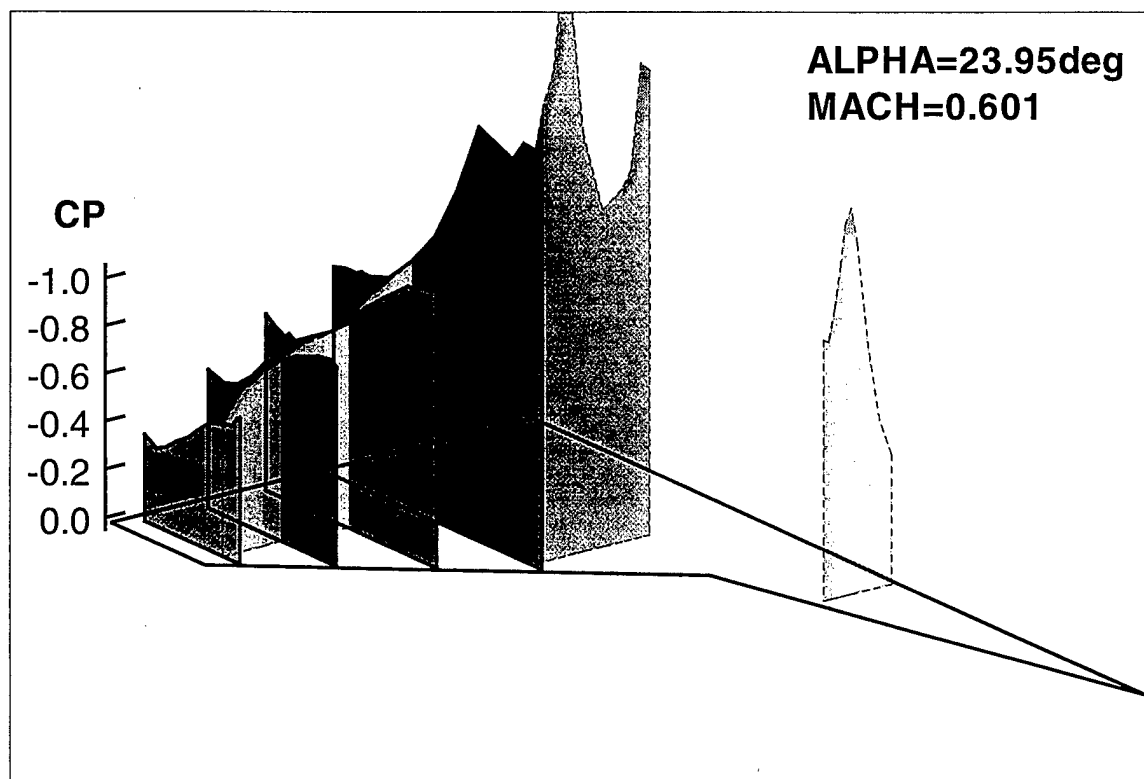


Sheet Position 9, Alpha = 21.9 deg
(Run ID = 79, Frame = -411)

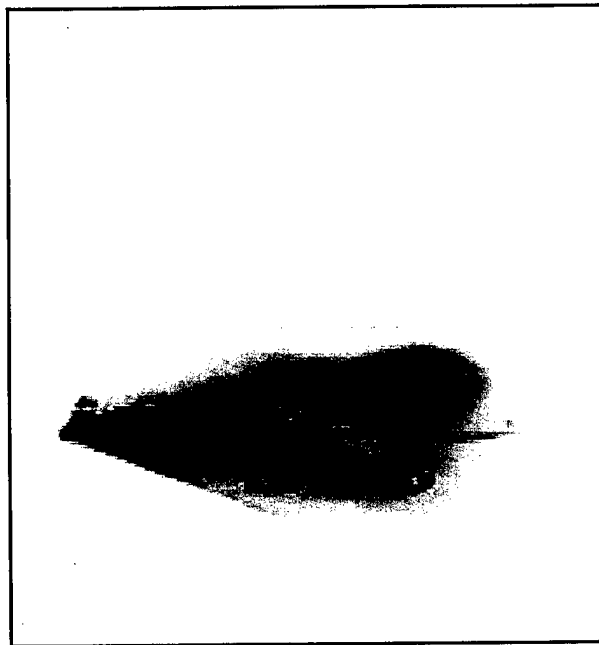


Sheet Position 9, Alpha = 23.1 deg
(Run ID = 79 Frame = -381)

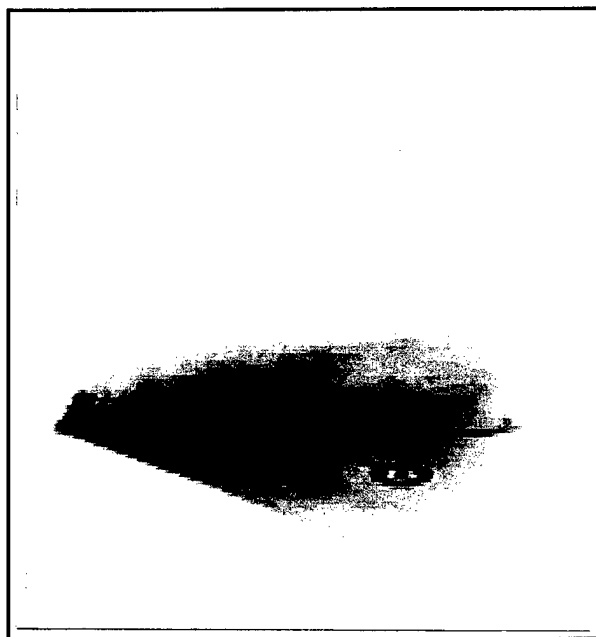
Figure 2.16 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.6$, Alpha = 21.9 deg and 23.1 deg



**Figure 2.17 - Steady Pressure Distributions at
Angles of 23.95 deg and 24.95 deg**

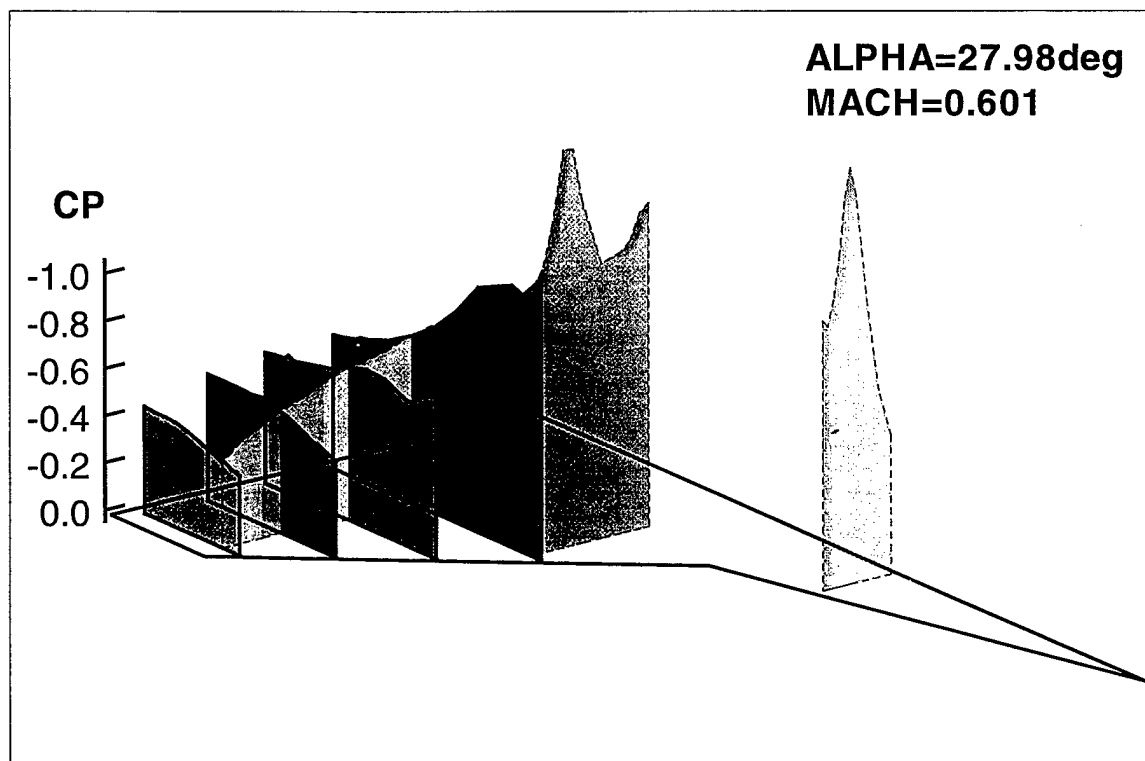
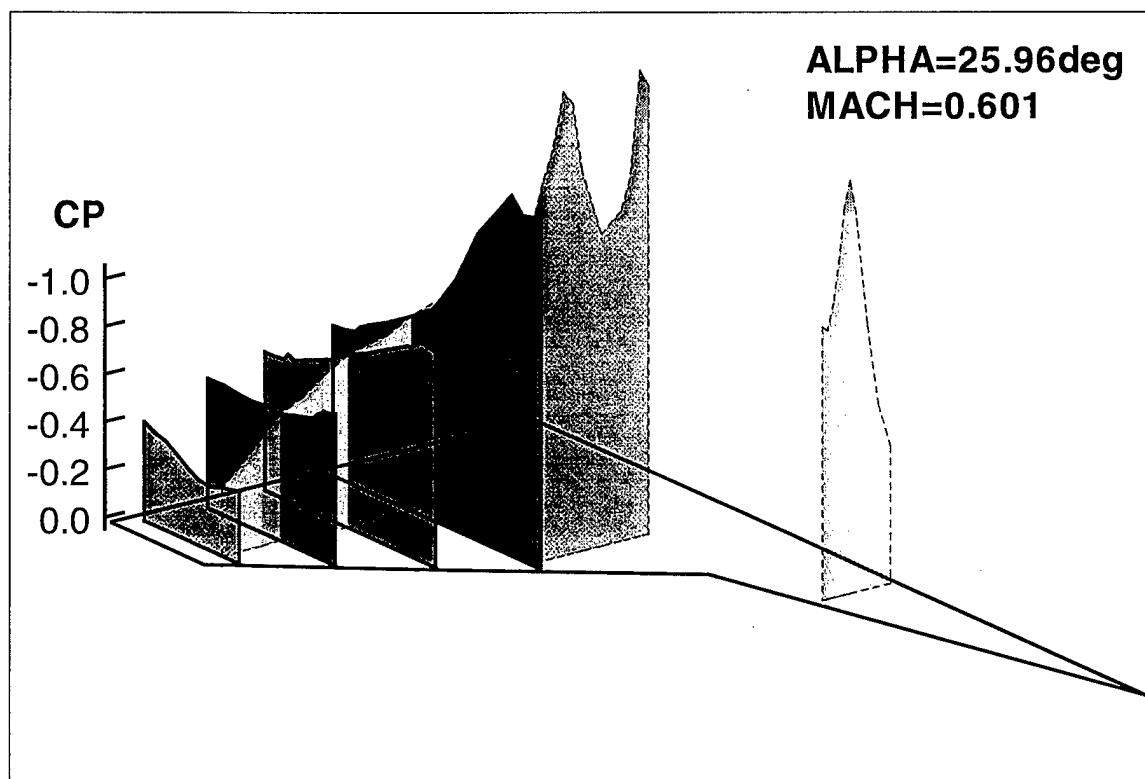


Sheet Position 9, Alpha = 24.3 deg
(Run ID = 79, Frame = -351)

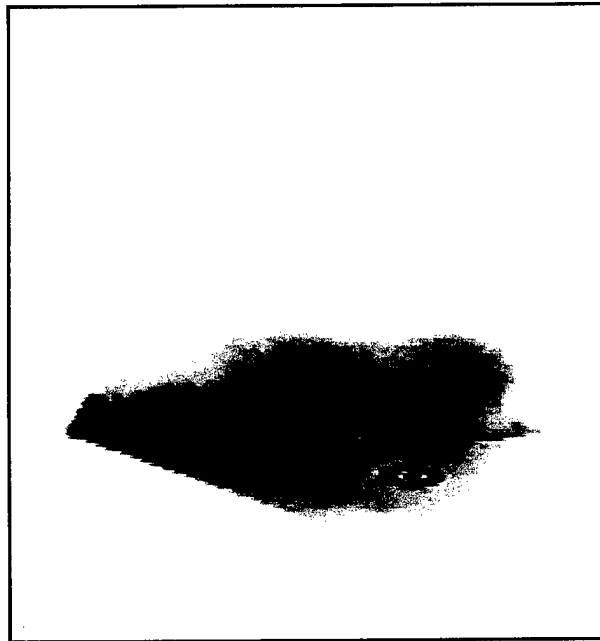


Sheet Position 9, Alpha = 25.5 deg
(Run ID = 79 Frame = -321)

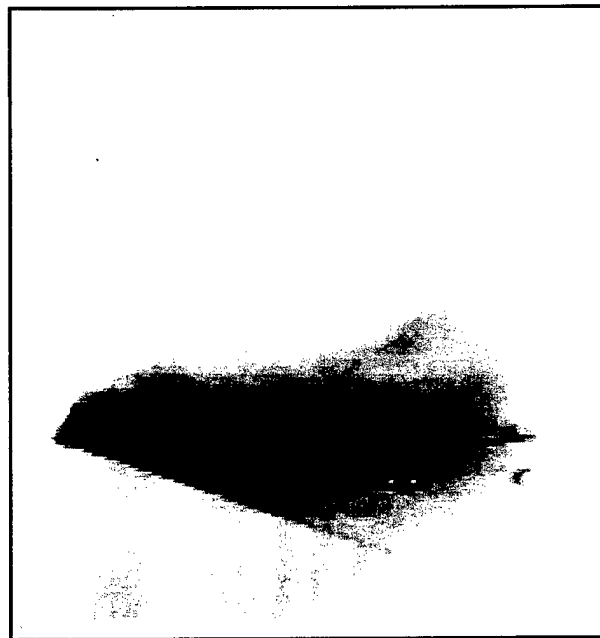
Figure 2.18 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.6$, Alpha = 24.3 deg and 25.5 deg



**Figure 2.19 - Steady Pressure Distributions at
Angles of 25.96 deg and 27.98 deg**



Sheet Position 9, Alpha = 26.3 deg
(Run ID = 79, Frame = -289)



Sheet Position 9, Alpha = 28.4 deg
(Run ID = 79 Frame = -260)

Figure 2.20 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.6$, Alpha = 26.3 deg and 28.4 deg

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2.0 HIGH SPEED VIDEO FLOW VISUALIZATION AND PRESSURE DATA FOR THE CLEAN WING AT $M = 0.9$, $\alpha = 6$ DEG TO 36 DEG

Individual frames from the high speed video data base (1000 frames per second) are presented in this section for two spanwise sheet positions, 8 and 9, as shown in Figure 3, below. With exception of the additional sheet position and higher Mach number, the data selection process and presentation format, as shown in the following Figures 4.01 through 4.28 are the same as were used in Section 1 at $M = 0.6$.

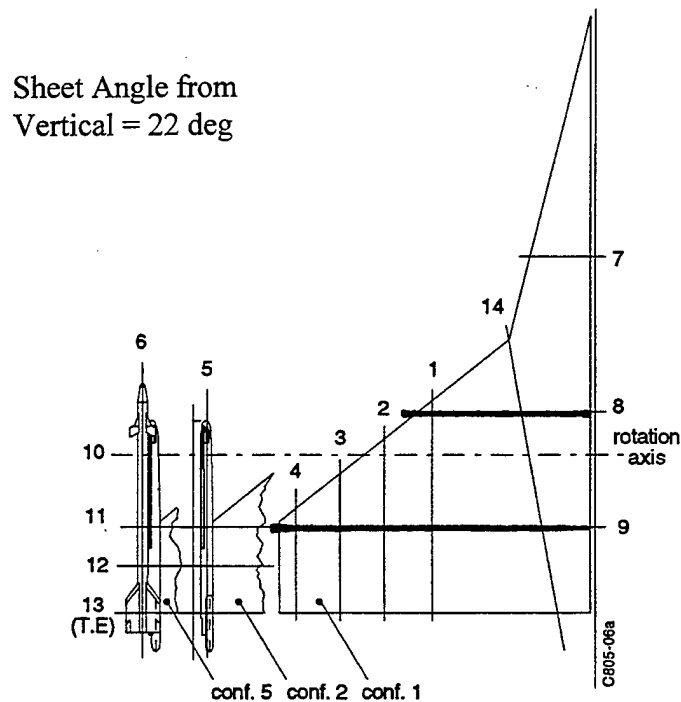
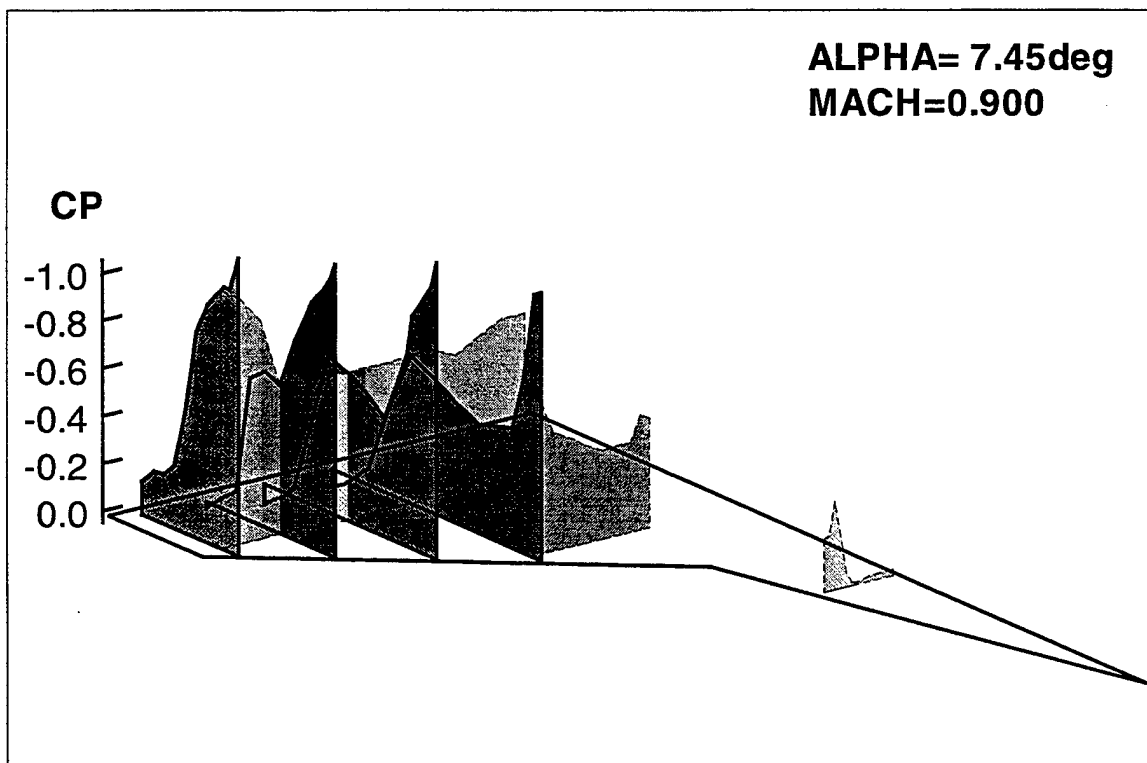
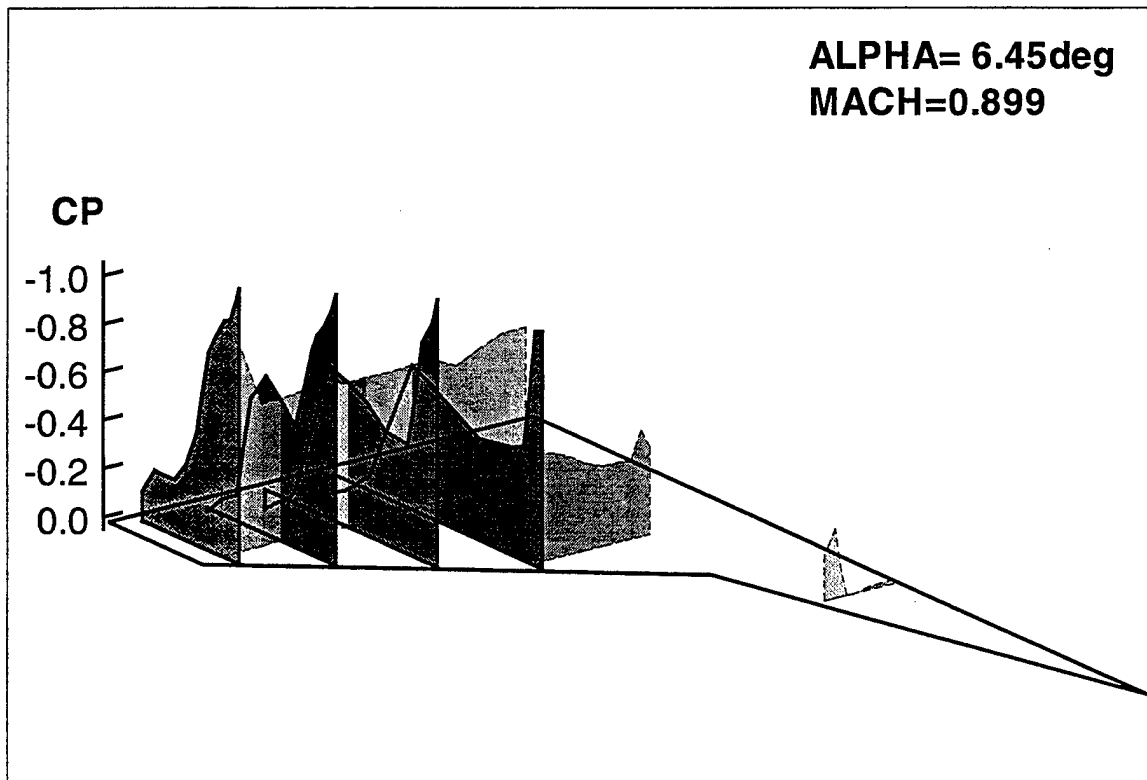
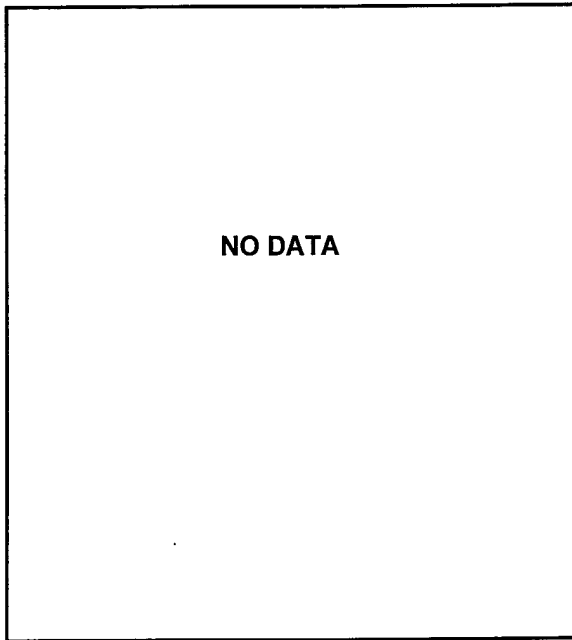


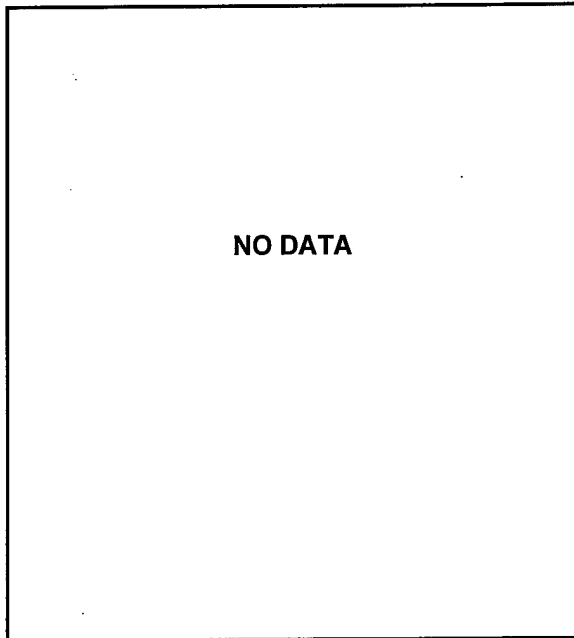
Figure 3 - Flow Visualization Sheet Locations for Figures 4, Clean Wing, $M = 0.9$, $\alpha = 6$ deg to 36 deg



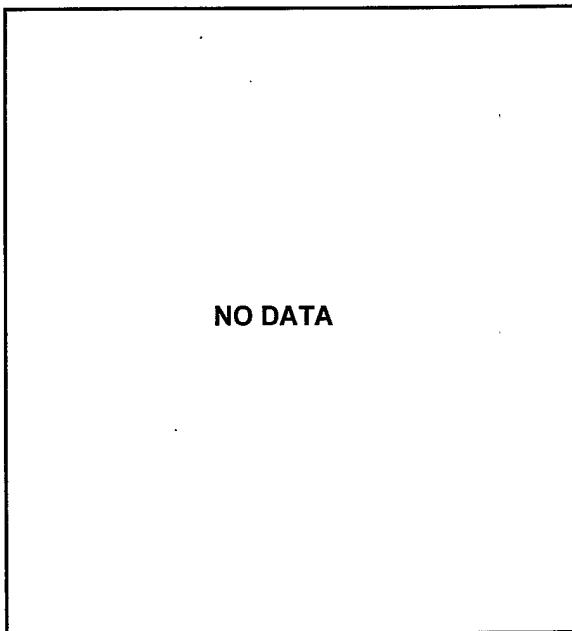
**Figure 4.01 - Steady Pressure Distributions at
Angles of 6.45 deg and 7.45 deg**



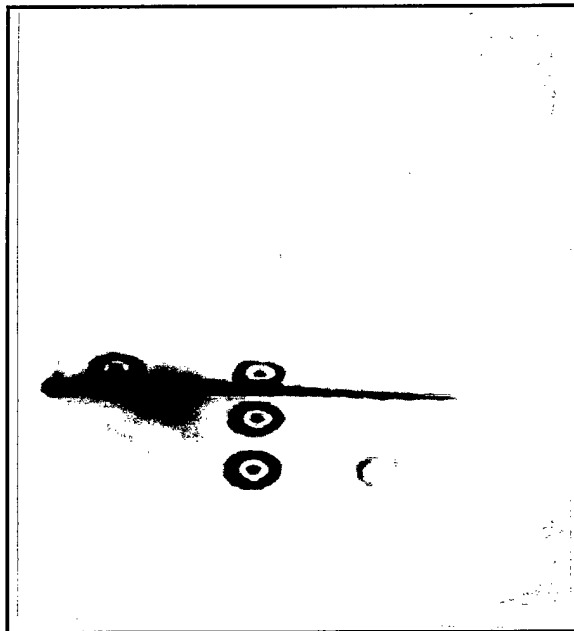
Sheet Position 8, Alpha = 6.4 deg
(Run ID = 64, Frame = xxx)



Sheet Position 9, Alpha = 6.4 deg
(Run ID = 69, Frame = xxx)

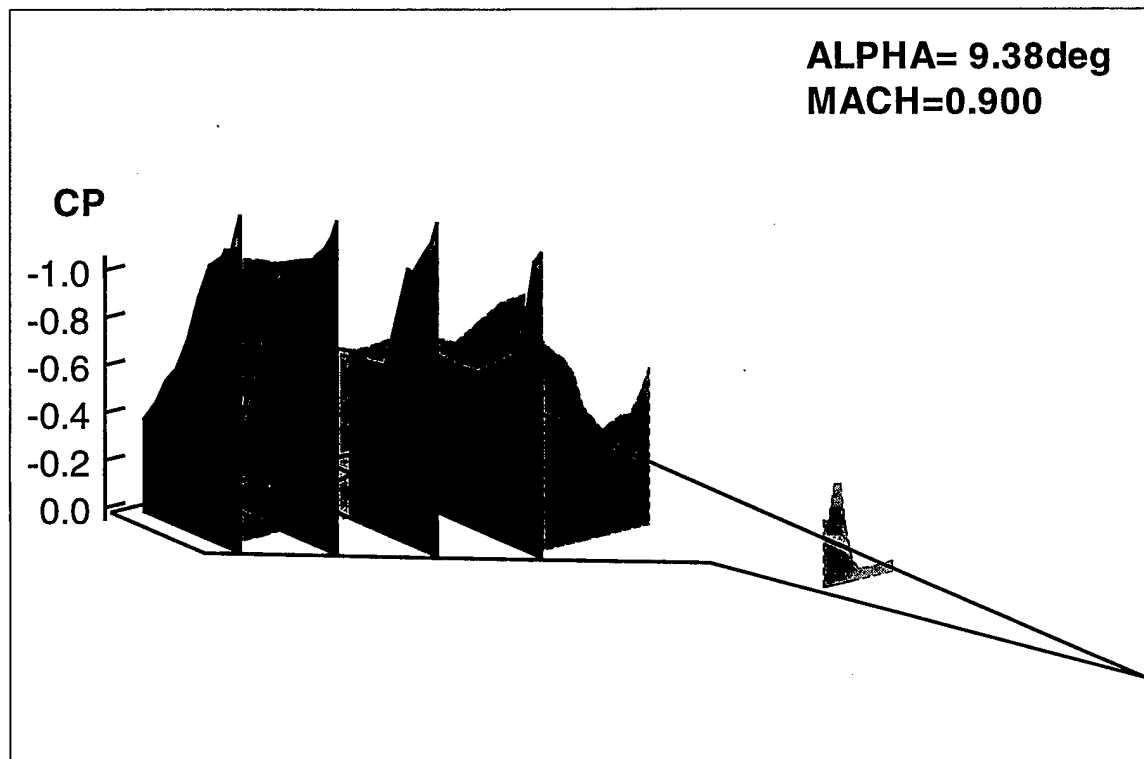
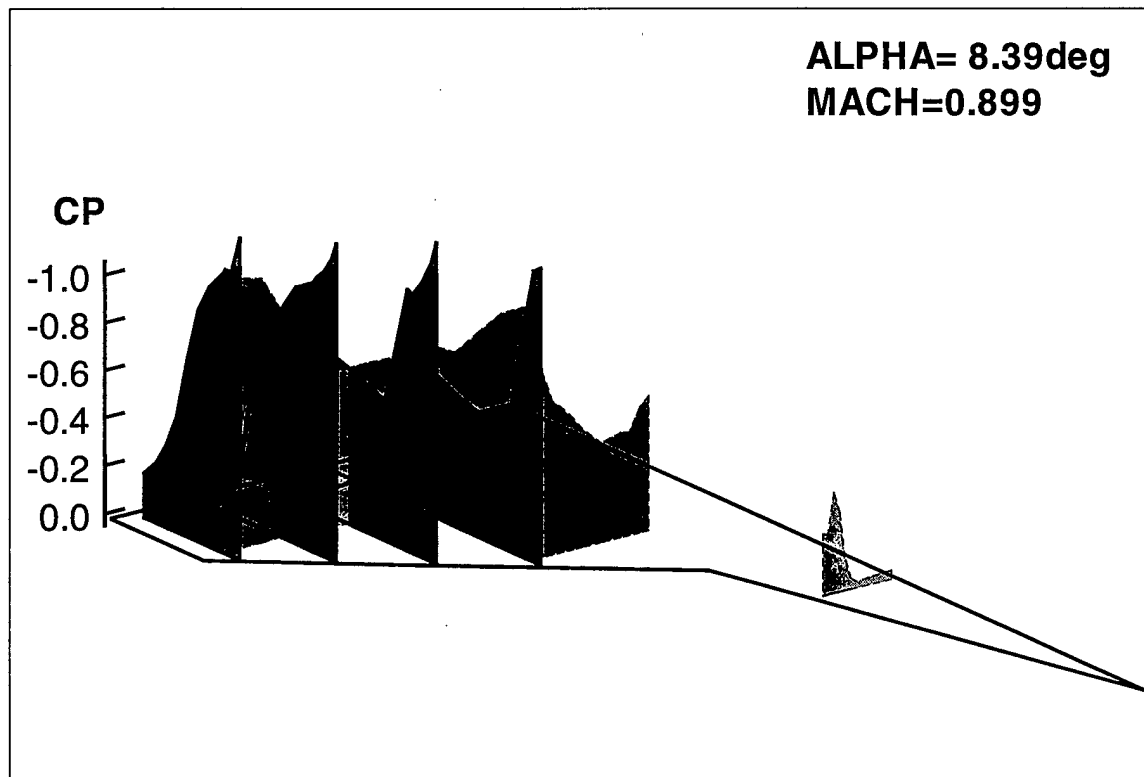


Sheet Position 8, Alpha = 7.4 deg
(Run ID = 64, Frame = xxx)

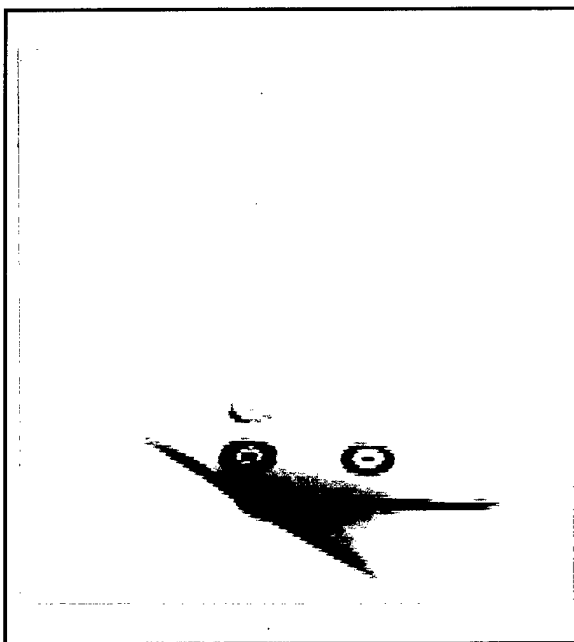


Sheet Position 9, Alpha = 7.5 deg
(Run ID = 69, Frame = -819)

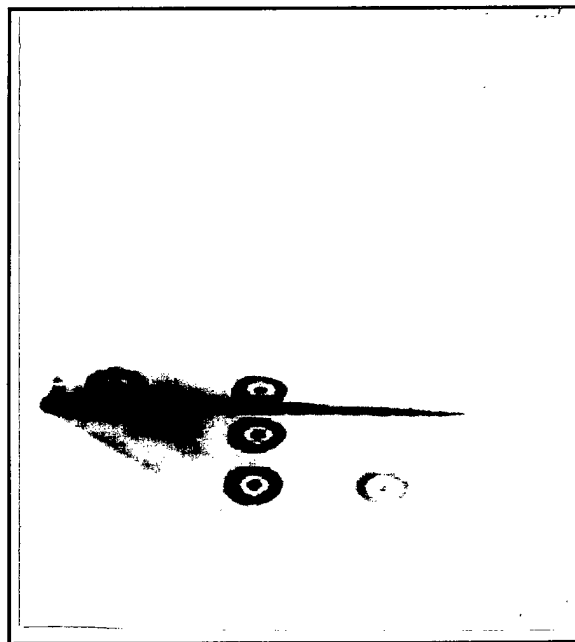
Figure 4.02 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 6.4 deg and 7.5 deg



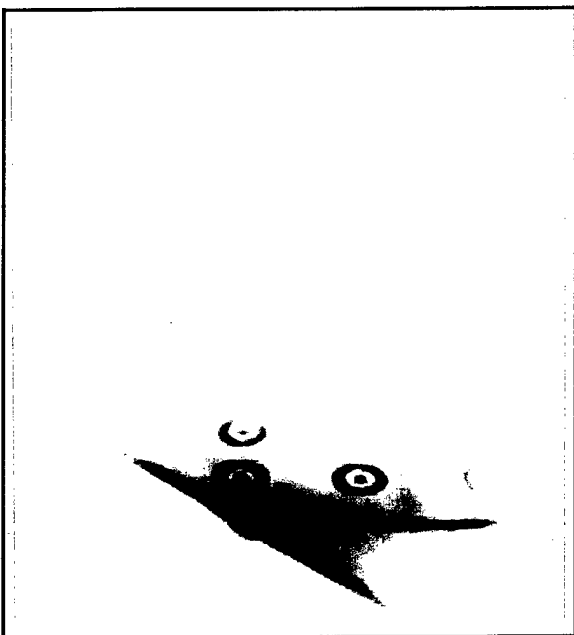
**Figure 4.03 - Steady Pressure Distributions at
Angles of 8.39 deg and 9.38 deg**



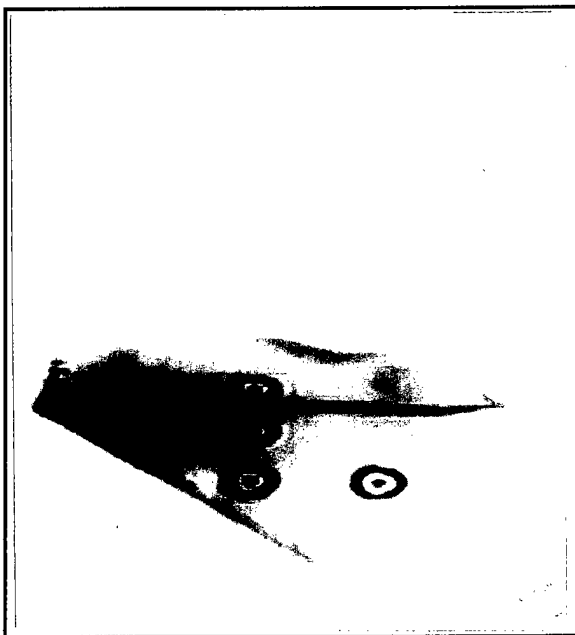
Sheet Position 8, Alpha = 8.5 deg
(Run ID = 64, Frame = -789)



Sheet Position 9, Alpha = 8.3 deg
(Run ID = 69, Frame = -787)

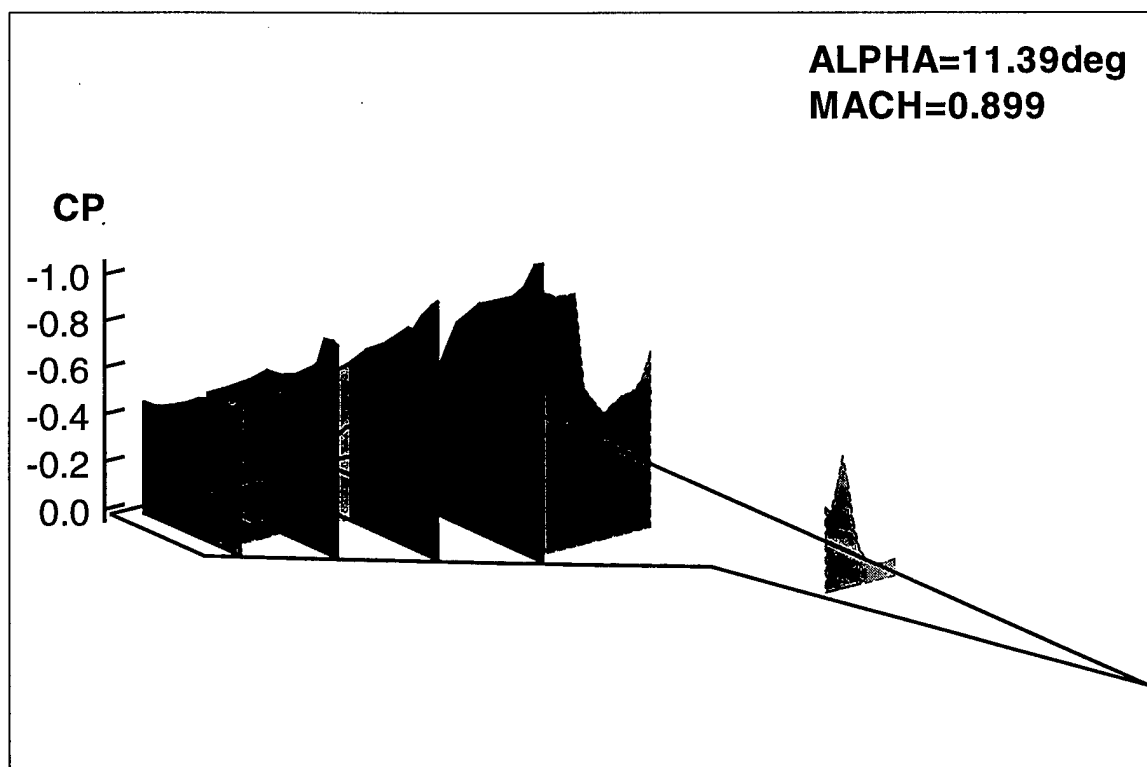
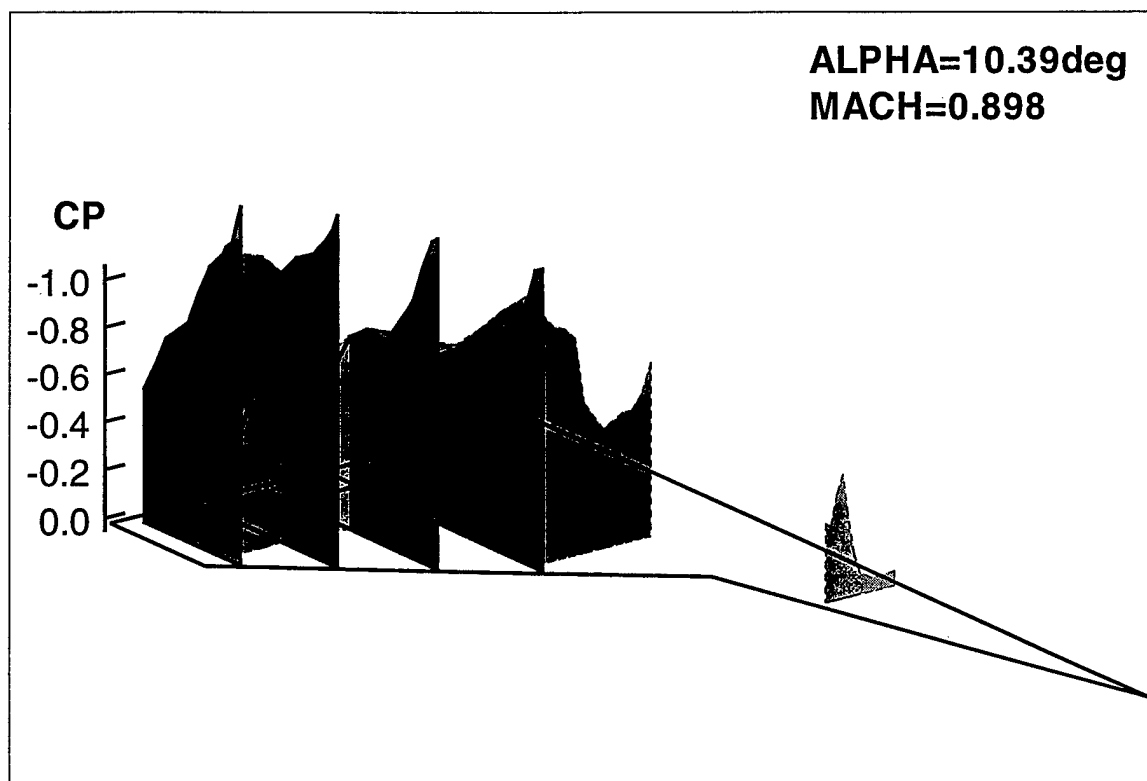


Sheet Position 8, Alpha = 9.2 deg
(Run ID = 64, Frame = -759)



Sheet Position 9, Alpha = 9.4 deg
(Run ID = 69, Frame = -759)

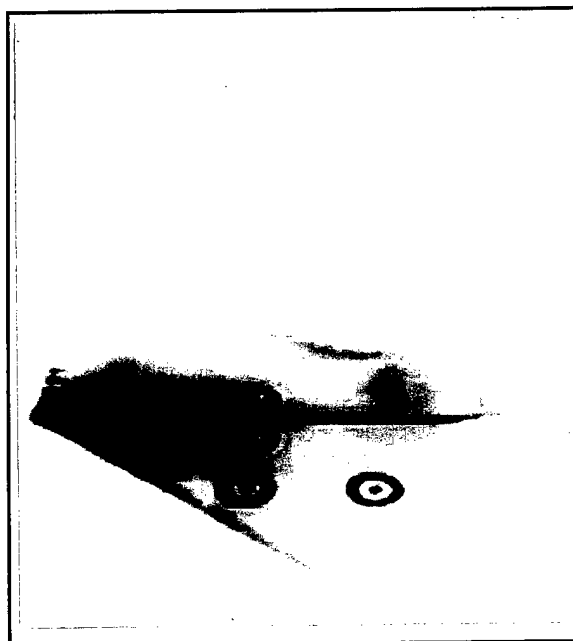
Figure 4.04 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 8.3 deg and 9.4 deg



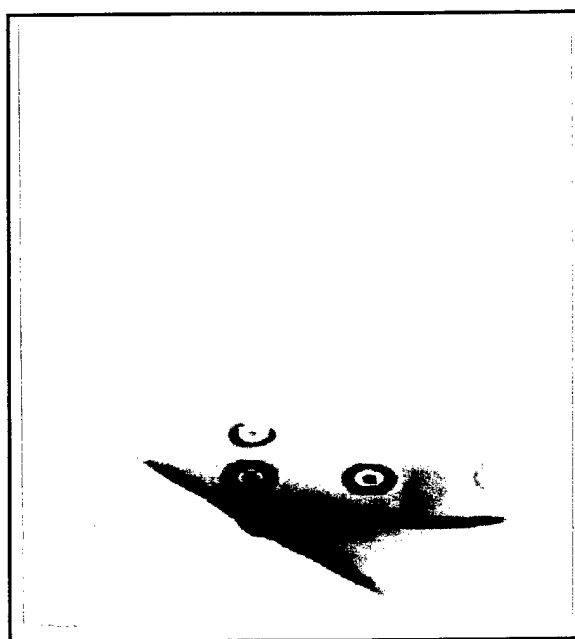
**Figure 4.05 - Steady Pressure Distributions at
Angles of 10.39 deg and 11.39 deg**



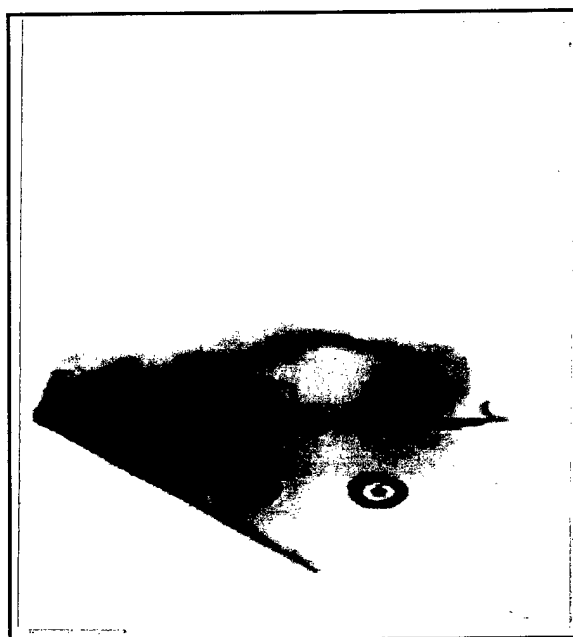
Sheet Position 8, Alpha = 10.4 deg
(Run ID = 64, Frame = -732)



Sheet Position 9, Alpha = 10.5 deg
(Run ID = 69, Frame = -729)

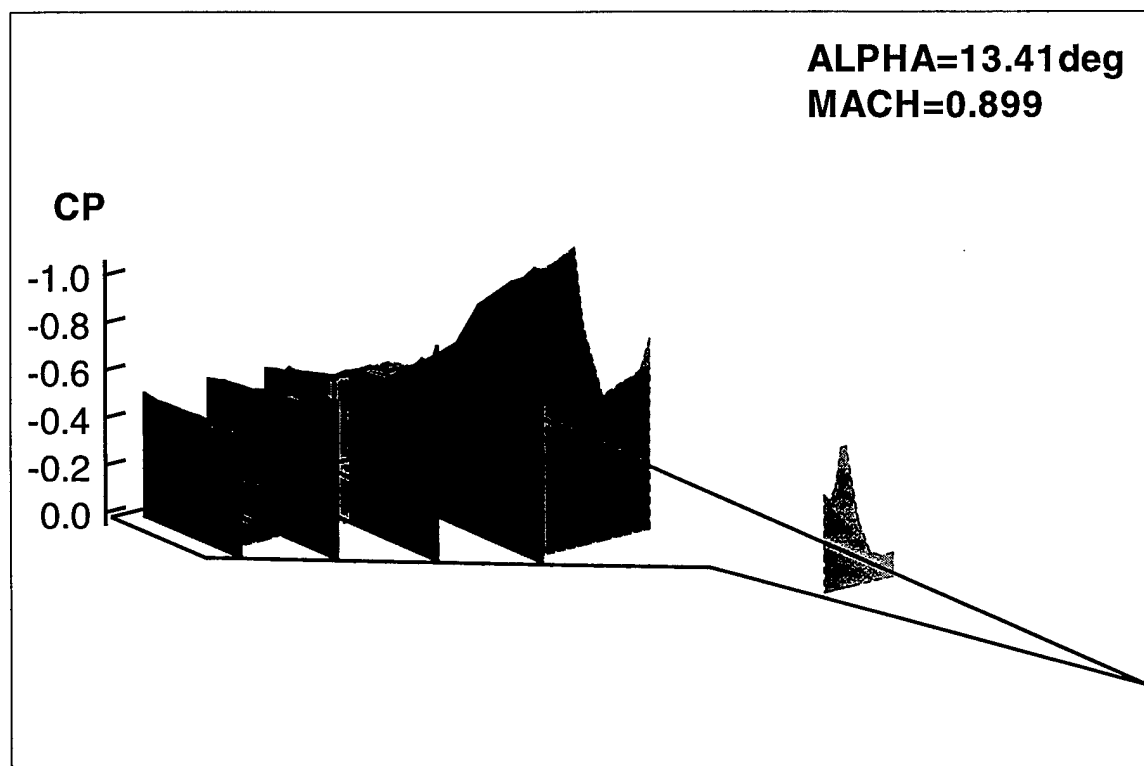
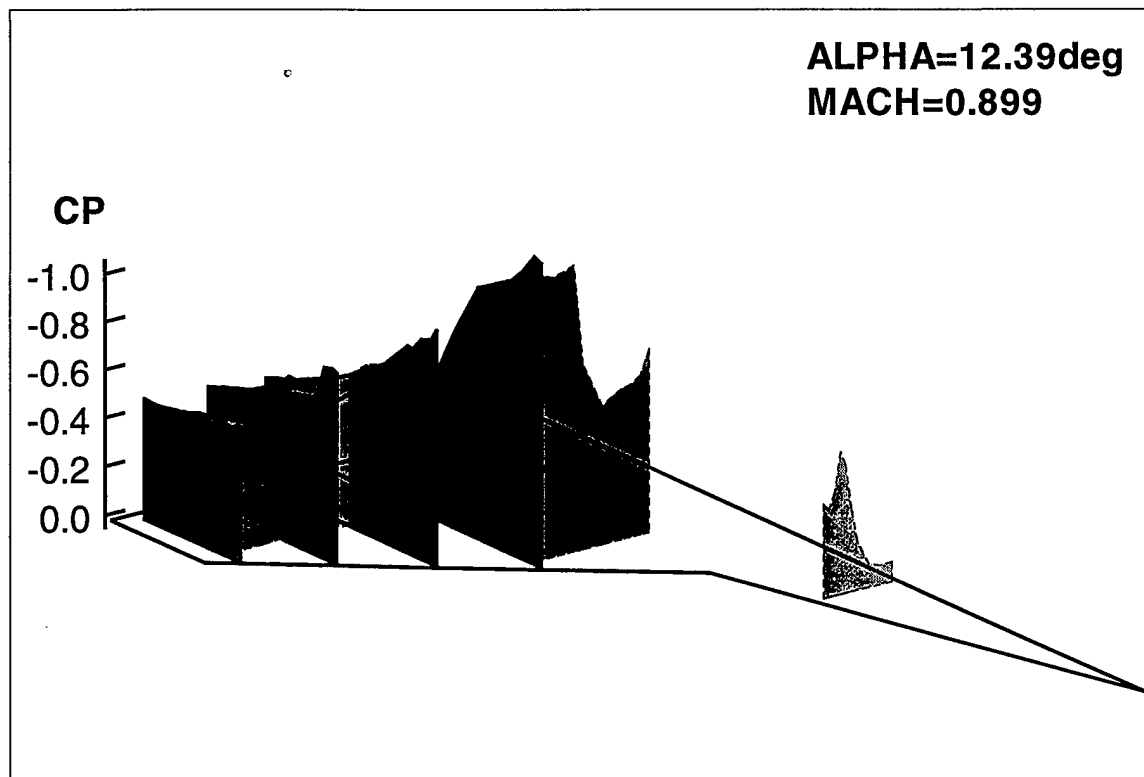


Sheet Position 8, Alpha = 11.5 deg
(Run ID = 64, Frame = -702)

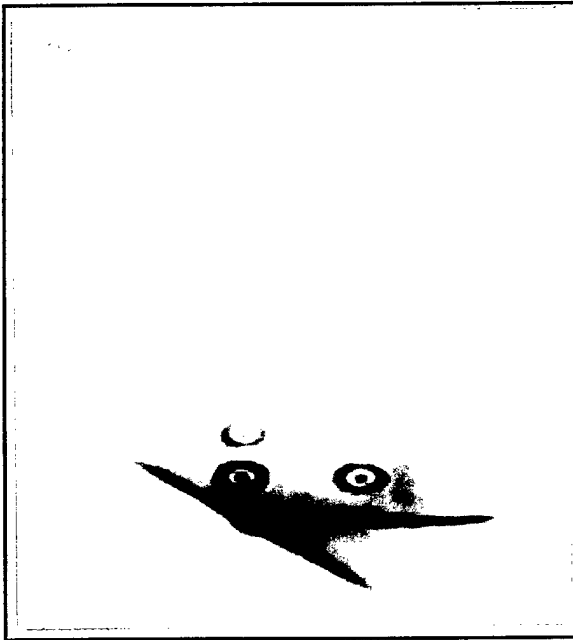


Sheet Position 9, Alpha = 11.6 deg
(Run ID = 69, Frame = -698)

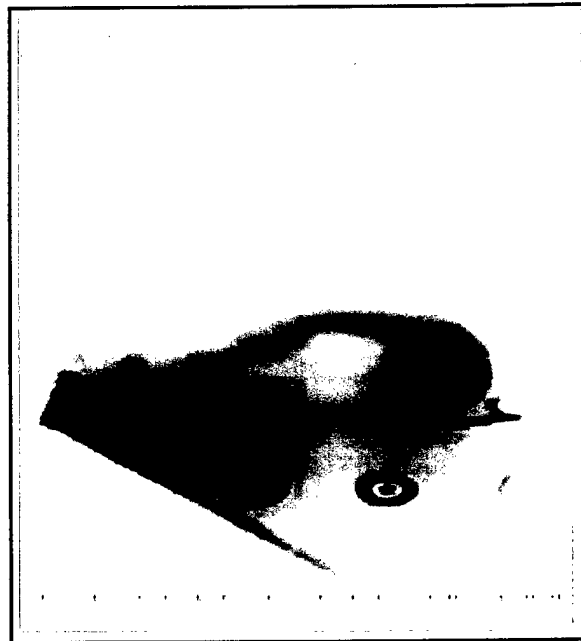
Figure 4.06 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 10.5 deg and 11.6 deg



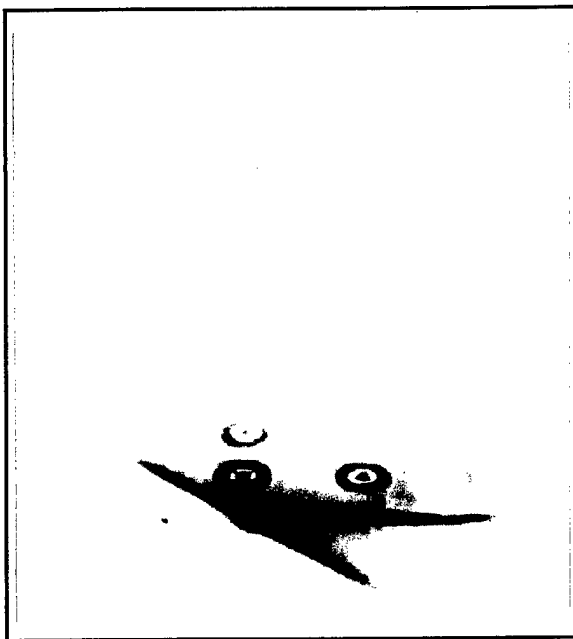
**Figure 4.07 - Steady Pressure Distributions at
Angles of 12.39 deg and 13.41 deg**



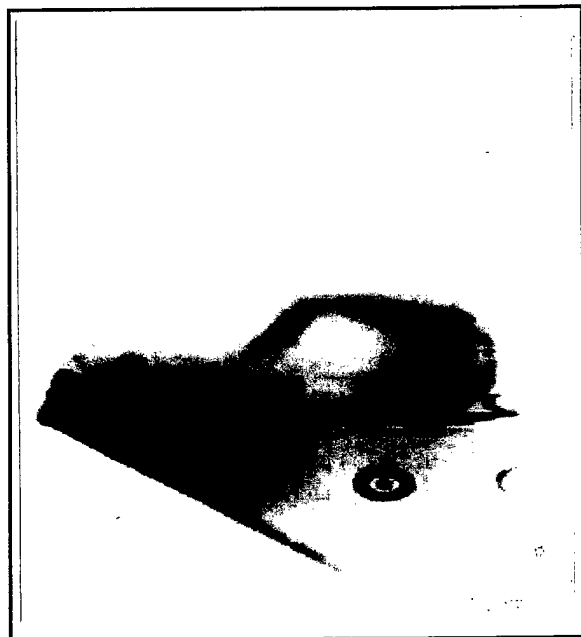
Sheet Position 8, Alpha = 12.6 deg
(Run ID = 64, Frame = -669)



Sheet Position 9, Alpha = 12.7 deg
(Run ID = 69, Frame = -661)

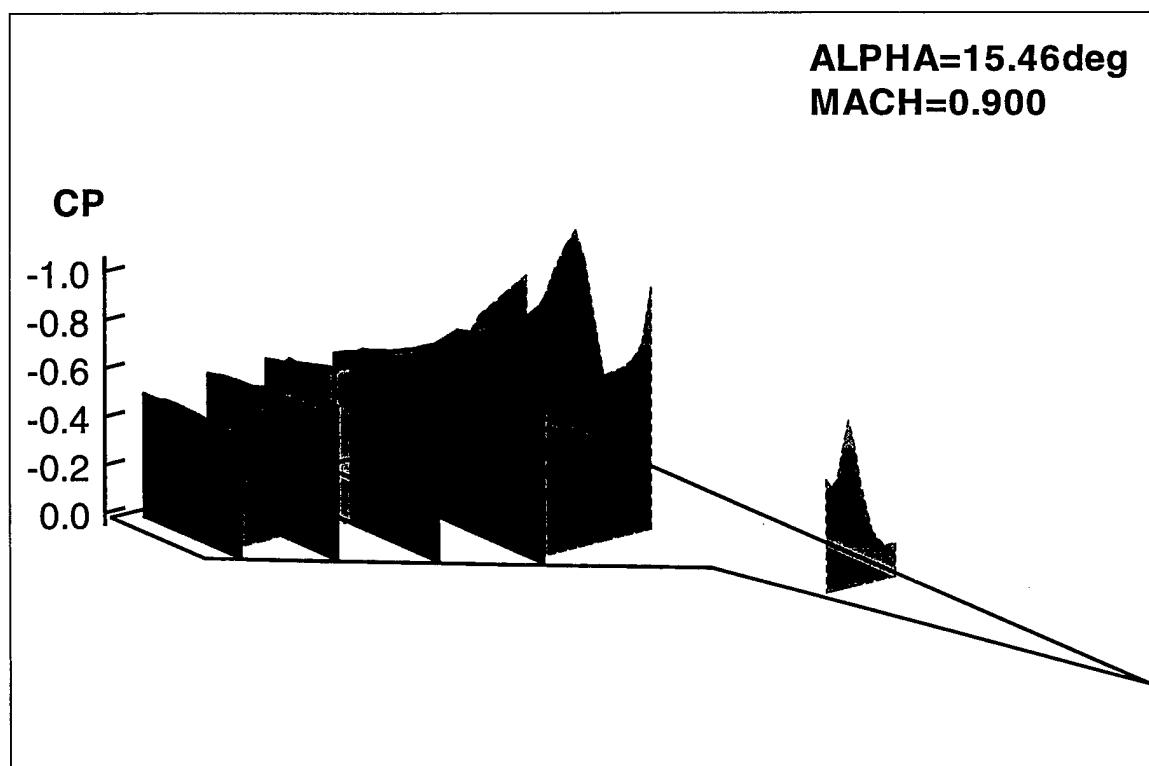
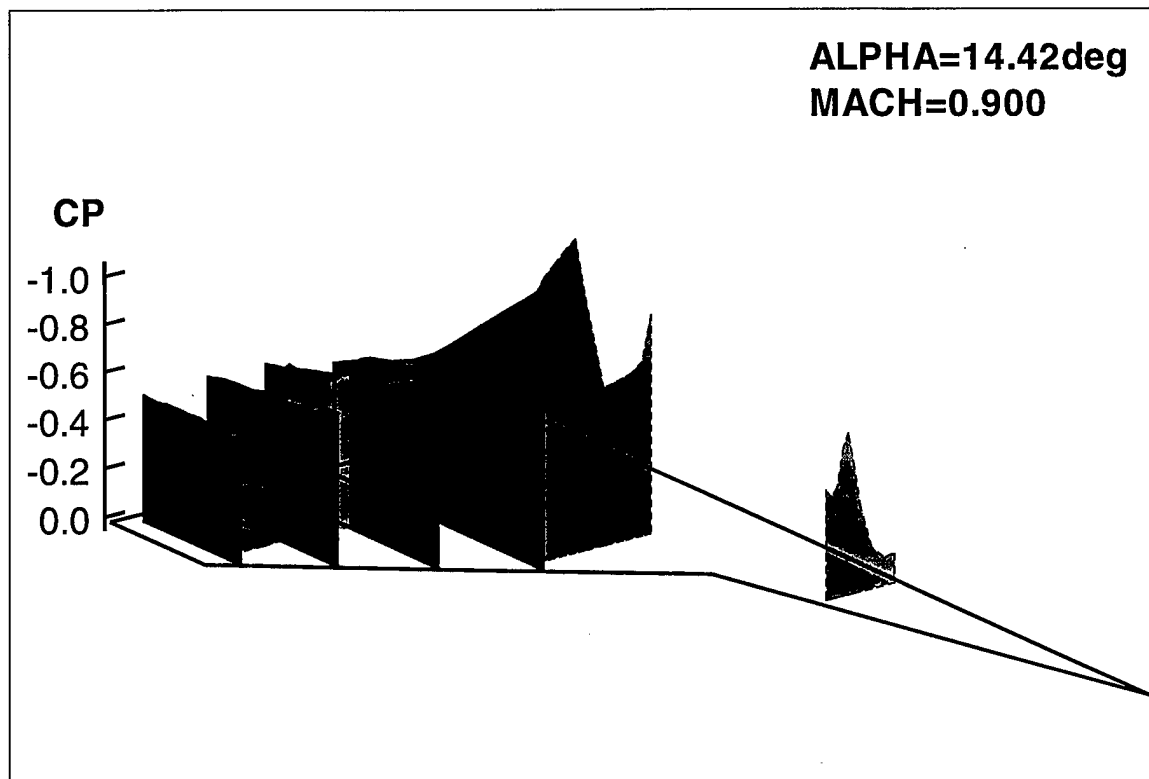


Sheet Position 8, Alpha = 13.3 deg
(Run ID = 64, Frame = -639)

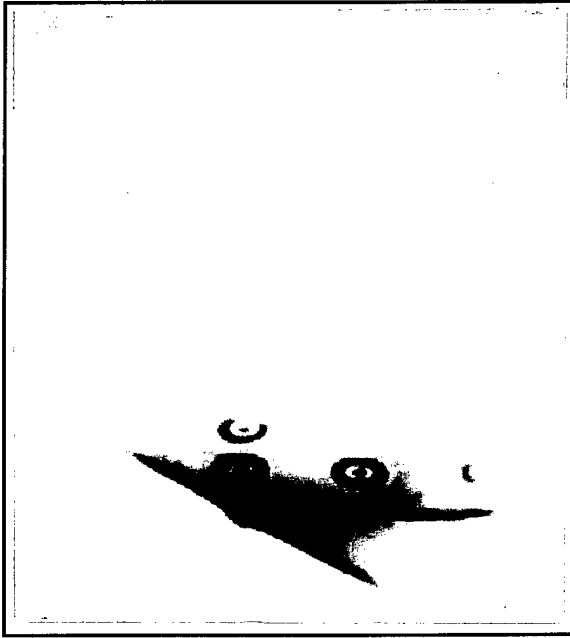


Sheet Position 9, Alpha = 13.5 deg
(Run ID = 69, Frame = -633)

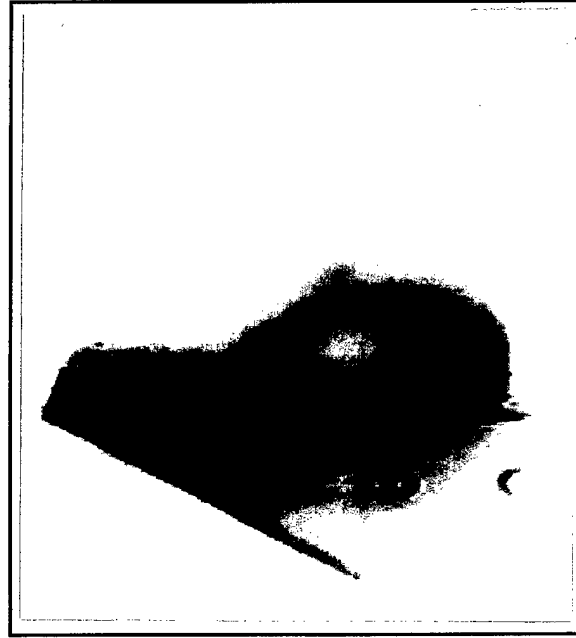
Figure 4.08 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 12.7 deg and 13.5 deg



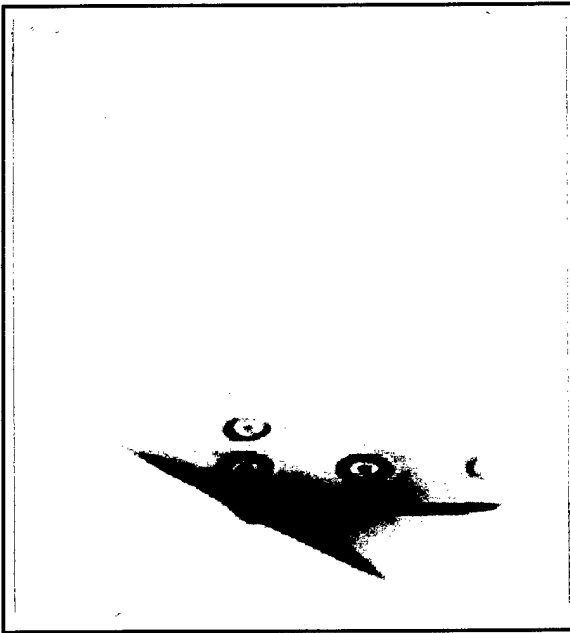
**Figure 4.09 - Steady Pressure Distributions at
Angles of 14.42 deg and 15.46 deg**



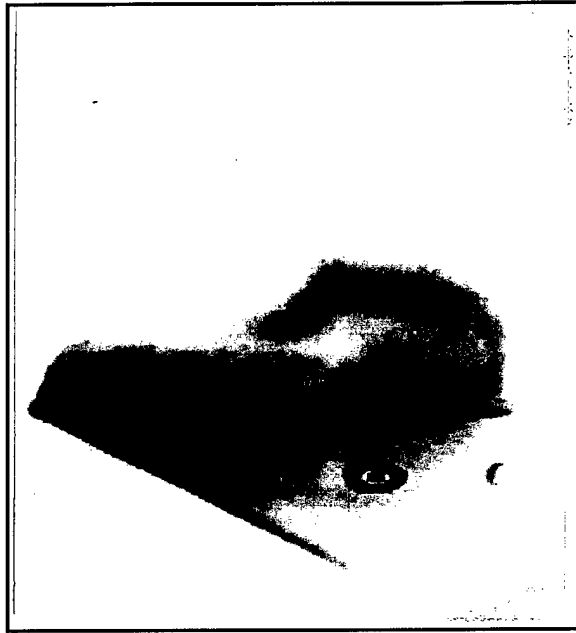
Sheet Position 8, Alpha = 14.4 deg
(Run ID = 64, Frame = -609)



Sheet Position 9, Alpha = 14.6 deg
(Run ID = 69, Frame = -608)

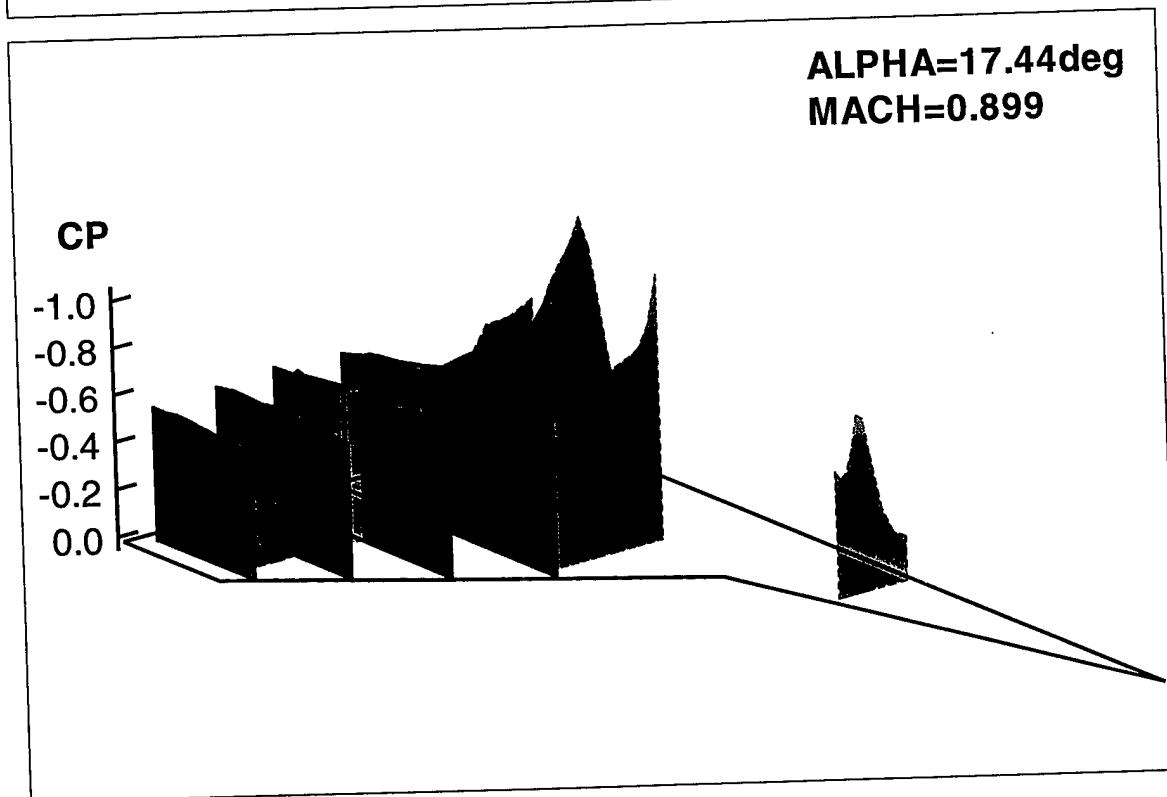
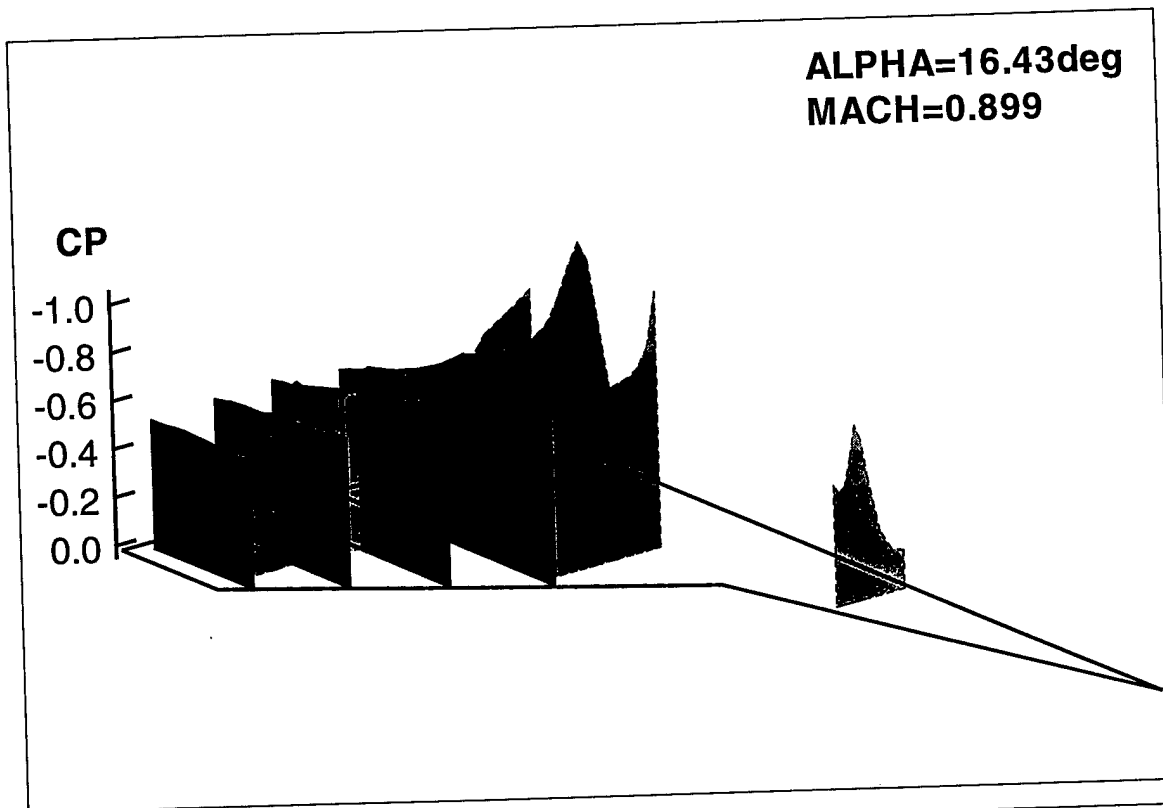


Sheet Position 8, Alpha = 15.5 deg
(Run ID = 64, Frame = -579)



Sheet Position 9, Alpha = 15.5 deg
(Run ID = 69, Frame = -576)

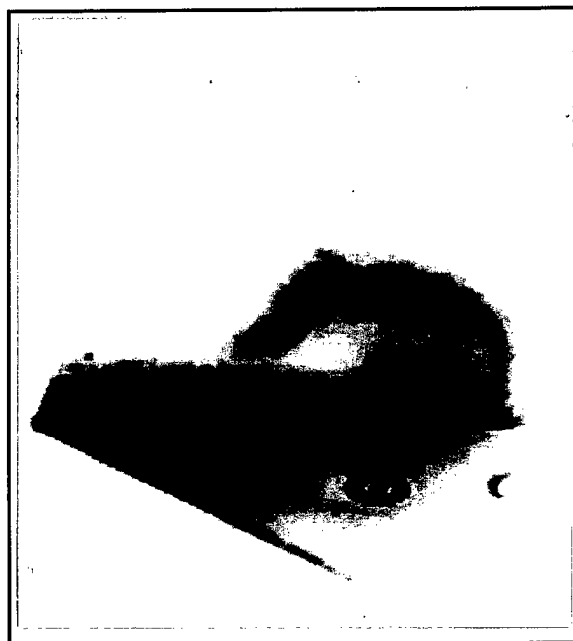
Figure 4.10 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 14.6 deg and 15.5 deg



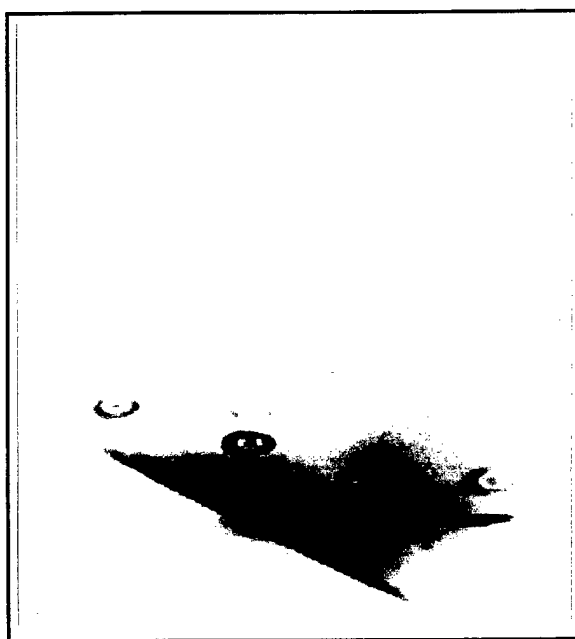
**Figure 4.11 - Steady Pressure Distributions at
Angles of 16.43 deg and 17.44 deg**



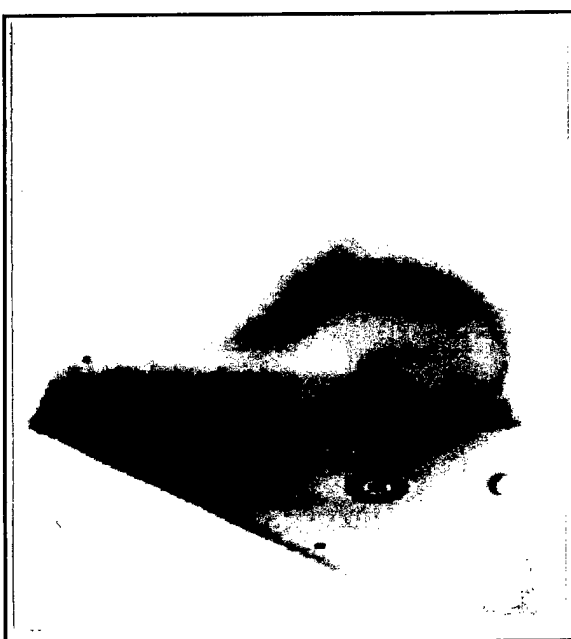
Sheet Position 8, Alpha = 16.6 deg
(Run ID = 64, Frame = -549)



Sheet Position 9, Alpha = 16.5 deg
(Run ID = 69, Frame = -555)

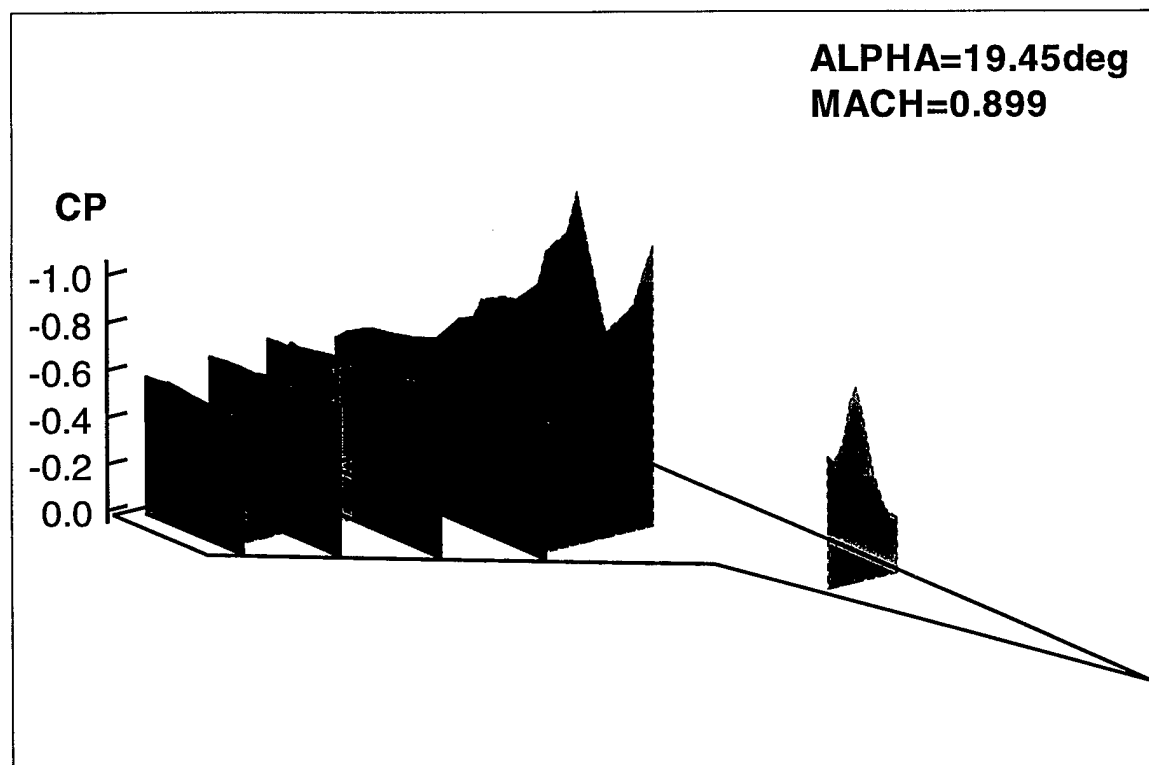
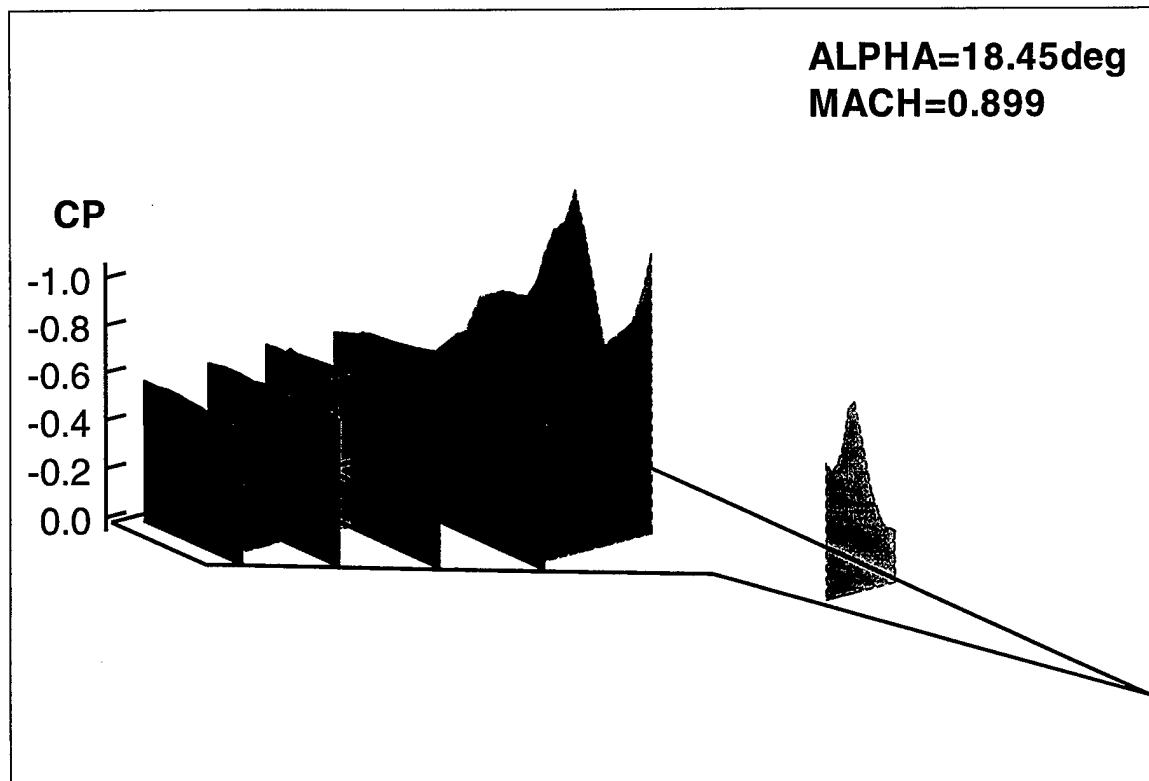


Sheet Position 8, Alpha = 17.6 deg
(Run ID = 64, Frame = -519)

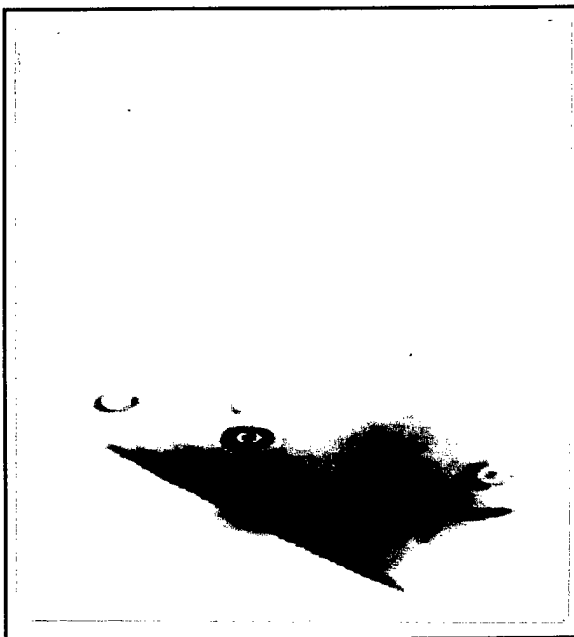


Sheet Position 9, Alpha = 17.6 deg
(Run ID = 69, Frame = -526)

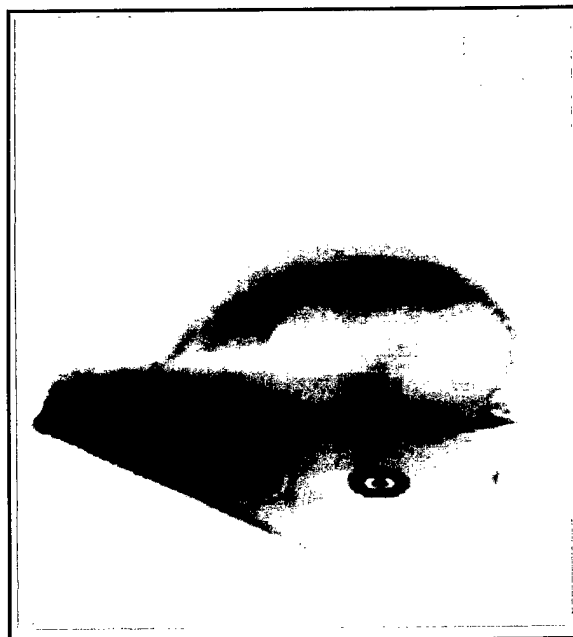
Figure 4.12 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 16.5 deg and 17.6 deg



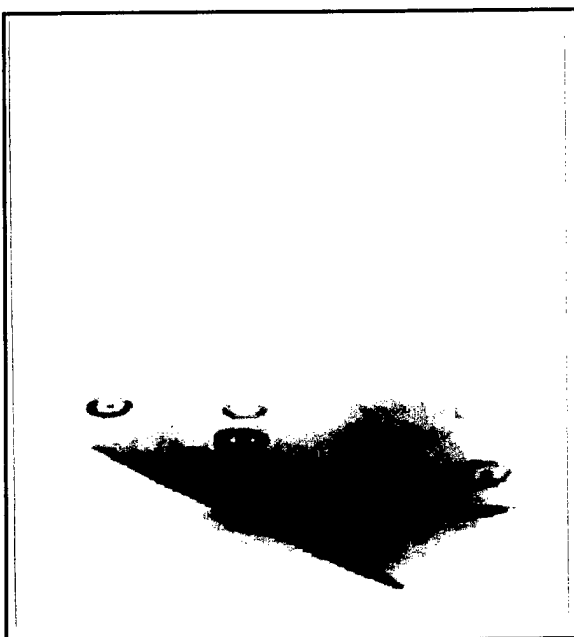
**Figure 4.13 - Steady Pressure Distributions at
Angles of 18.45 deg and 19.45 deg**



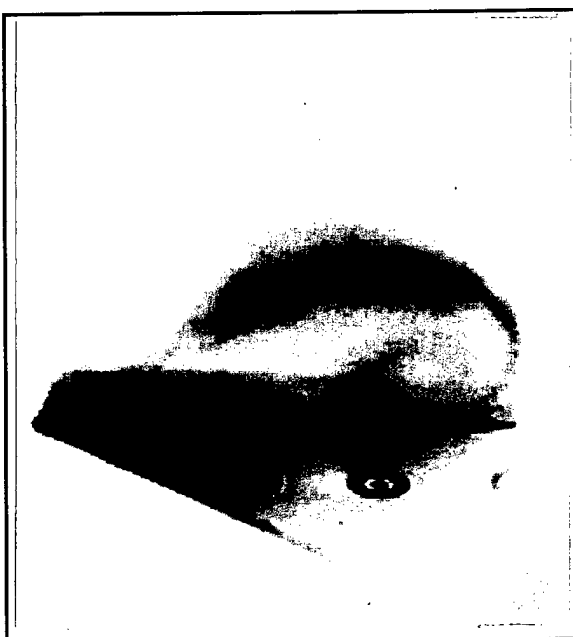
Sheet Position 8, Alpha = 18.6 deg
(Run ID = 64, Frame = -489)



Sheet Position 9, Alpha = 18.5 deg
(Run ID = 69, Frame = -490)

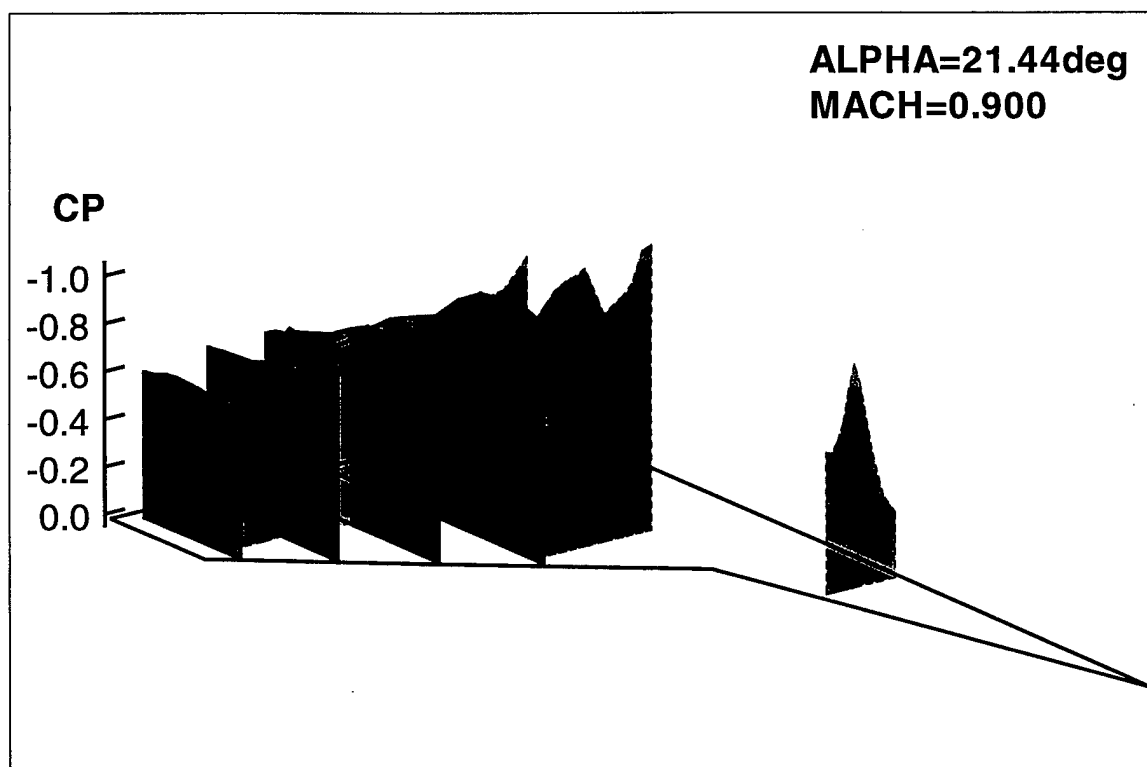
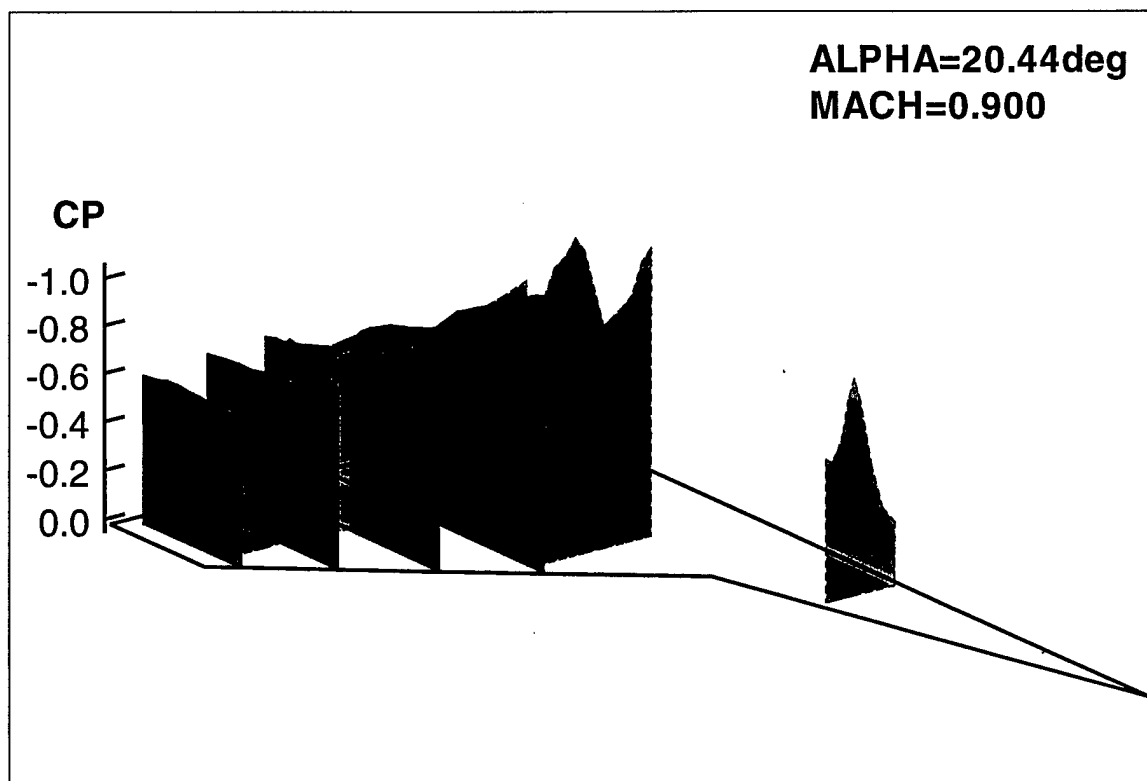


Sheet Position 8, Alpha = 19.8 deg
(Run ID = 64, Frame = -459)

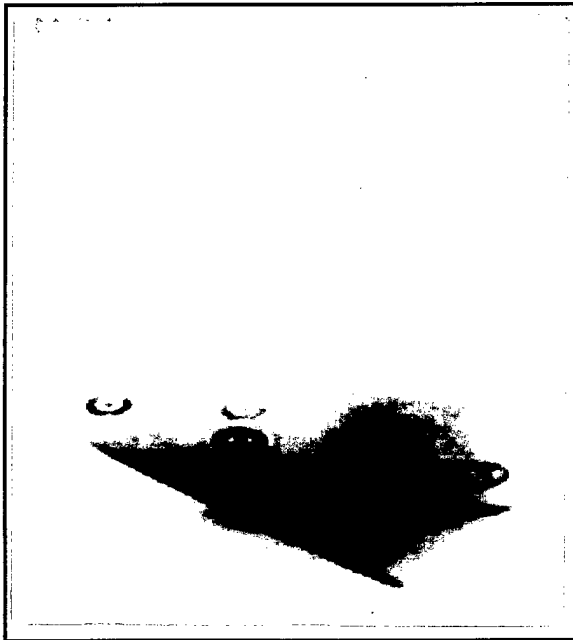


Sheet Position 9, Alpha = 19.4 deg
(Run ID = 69, Frame = -467)

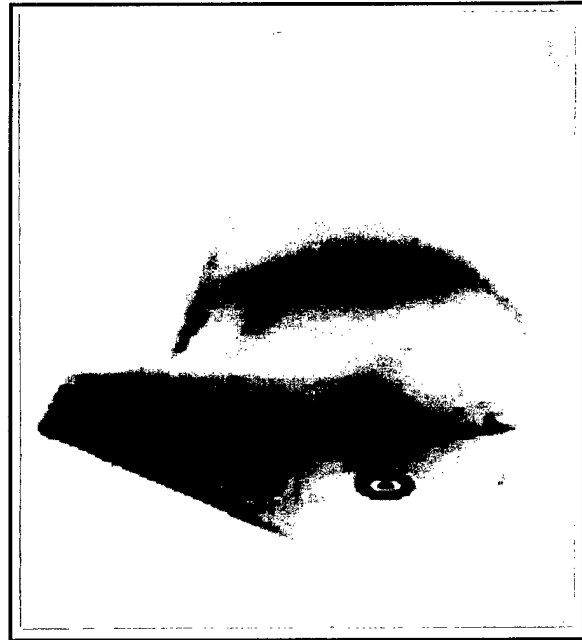
Figure 4.14 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 18.5 deg and 19.4 deg



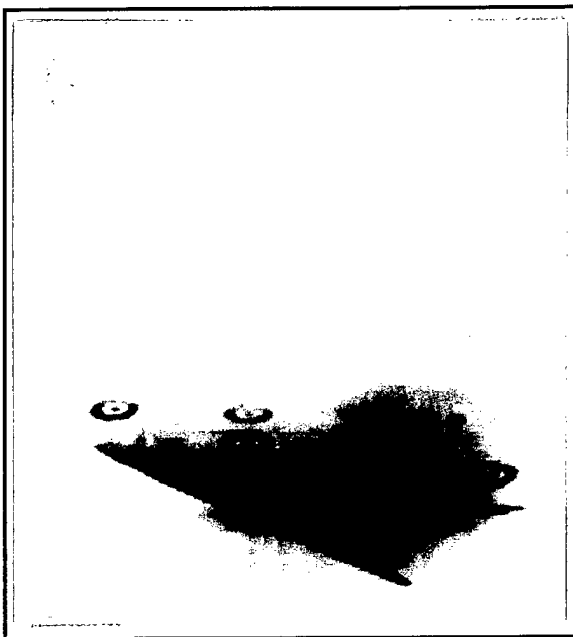
**Figure 4.15 - Steady Pressure Distributions at
Angles of 20.44 deg and 21.44 deg**



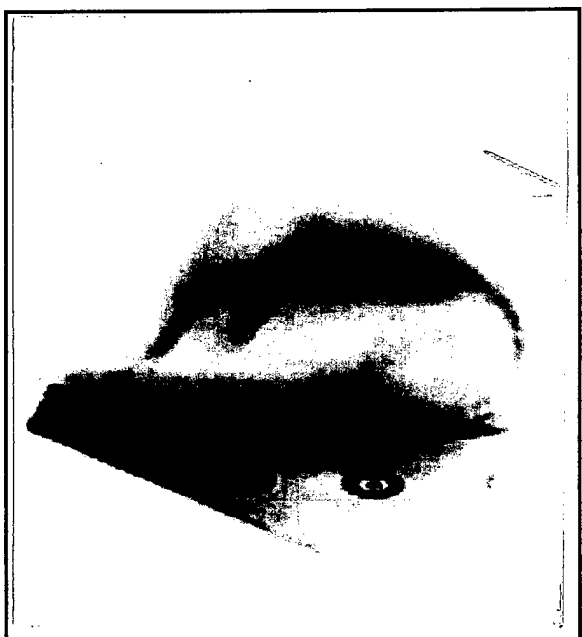
Sheet Position 8, Alpha = 20.6 deg
(Run ID = 64, Frame = -429)



Sheet Position 9, Alpha = 20.5 deg
(Run ID = 69, Frame = -439)

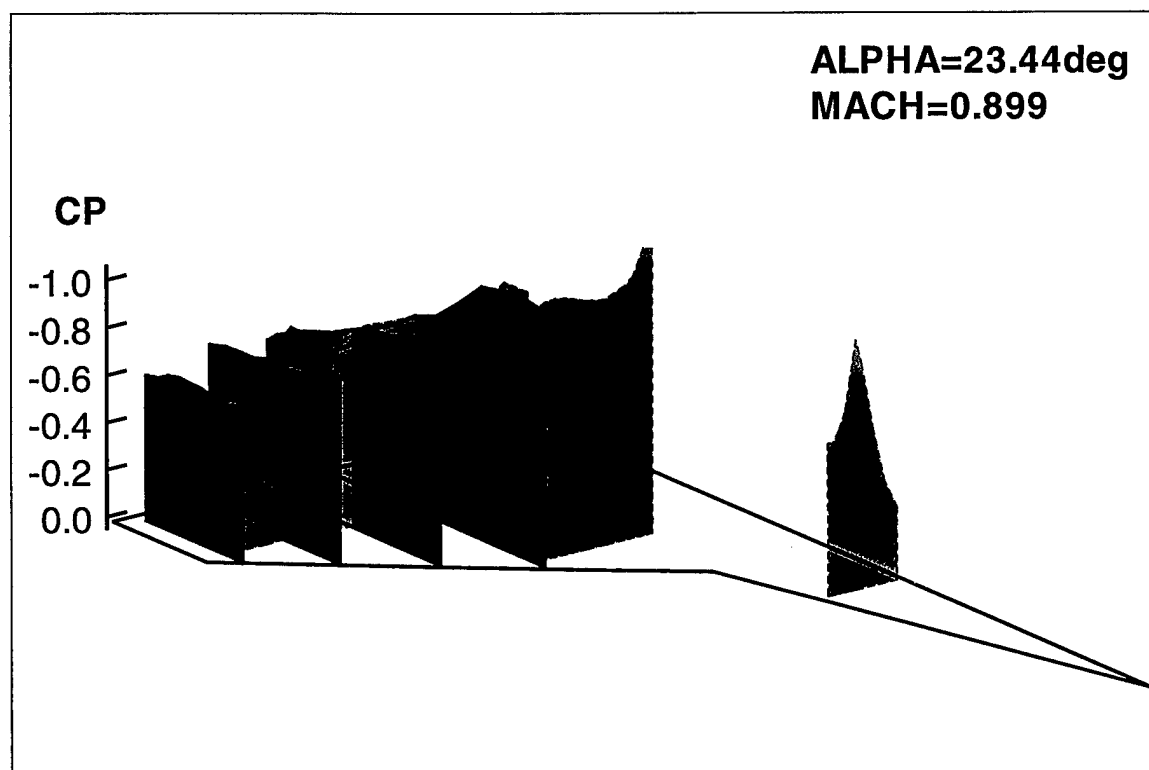
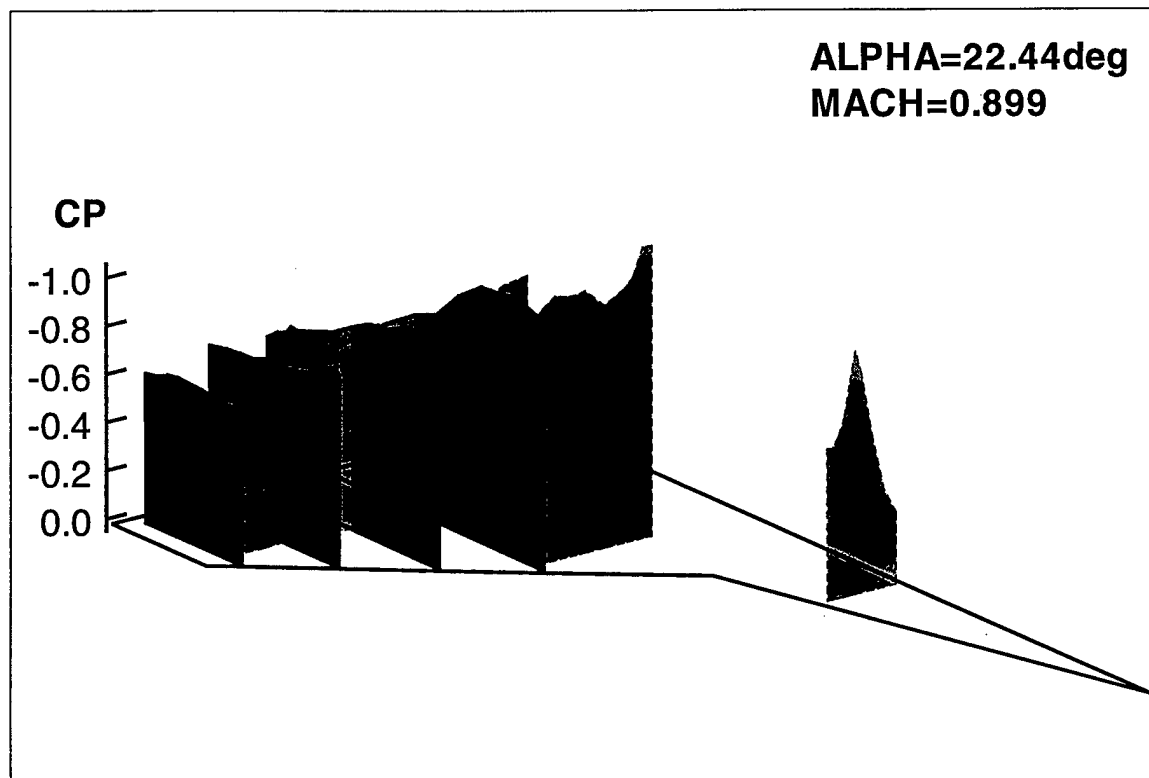


Sheet Position 8, Alpha = 21.7 deg
(Run ID = 64, Frame = -401)

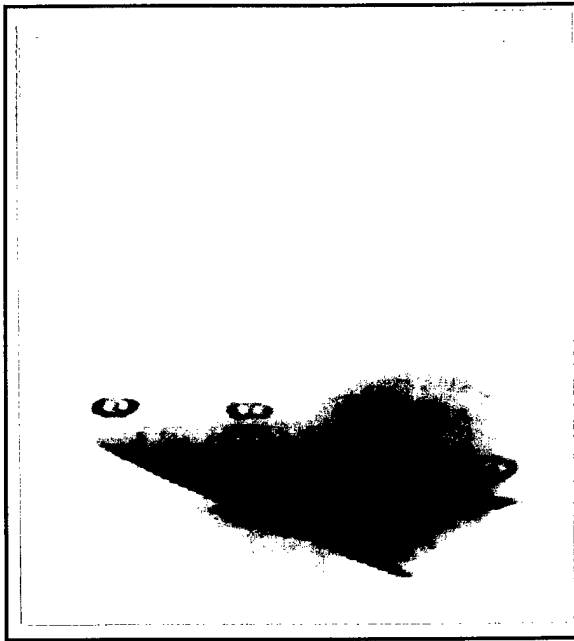


Sheet Position 9, Alpha = 21.6 deg
(Run ID = 69, Frame = -409)

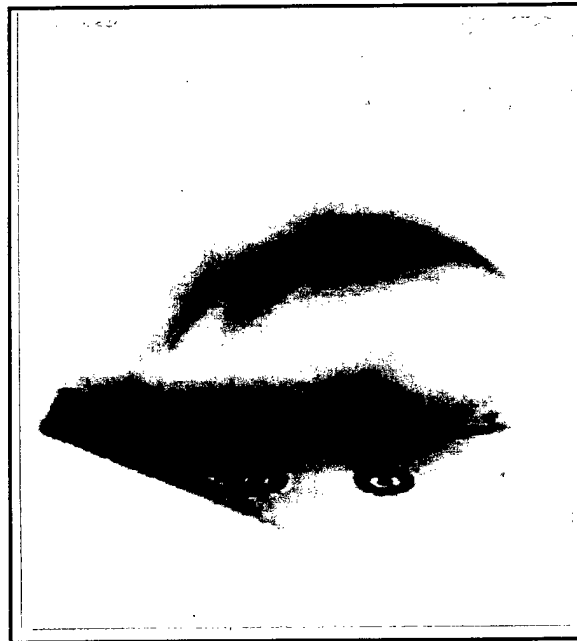
Figure 4.16 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 20.5 deg and 21.6 deg



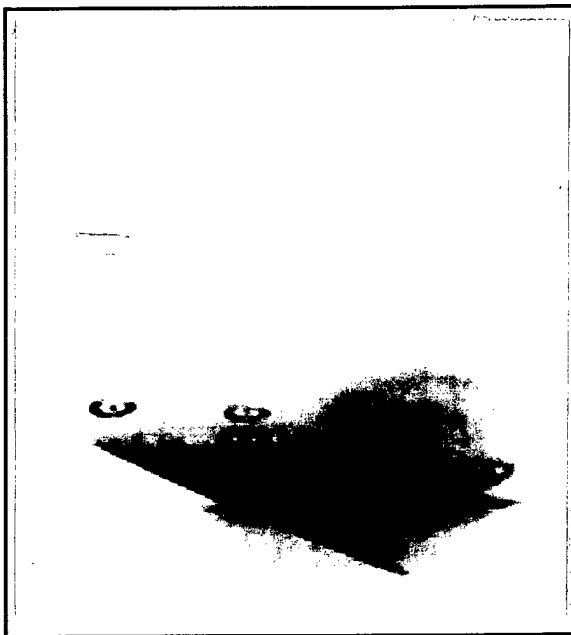
**Figure 4.17 - Steady Pressure Distributions at
Angles of 22.44 deg and 23.44 deg**



Sheet Position 8, Alpha = 22.5 deg
(Run ID = 64, Frame = -375)



Sheet Position 9, Alpha = 22.4 deg
(Run ID = 69, Frame = -379)

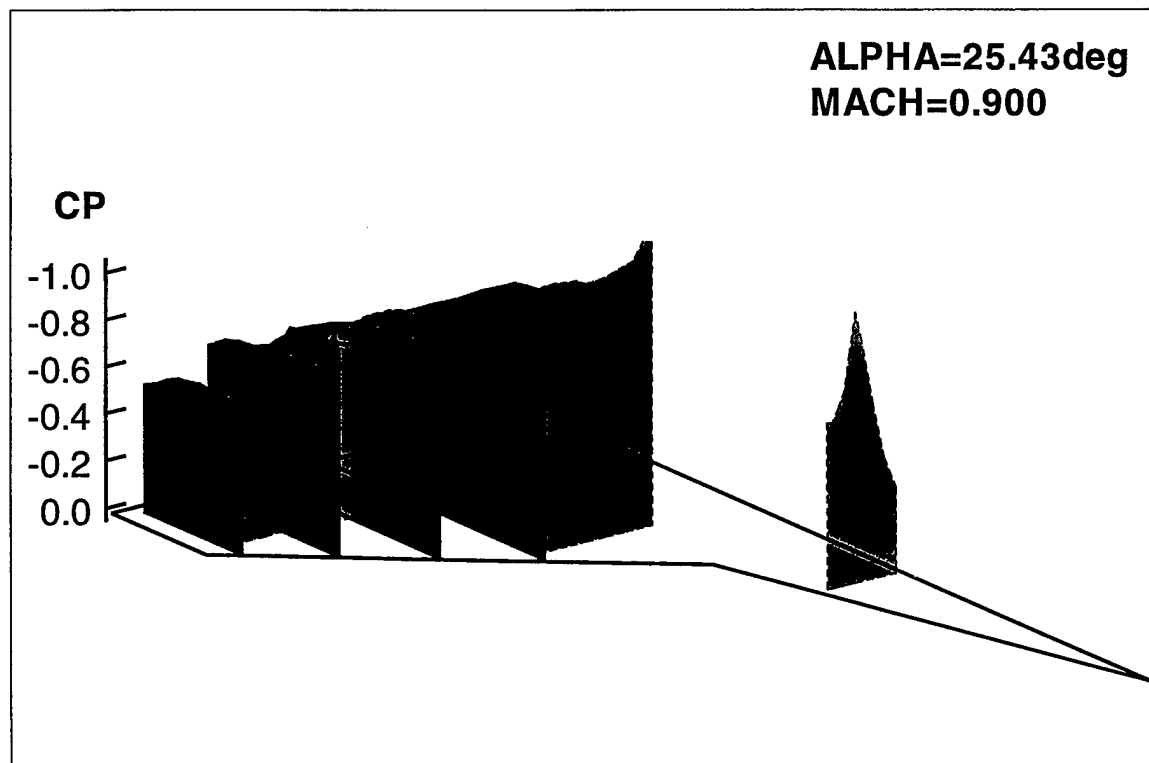
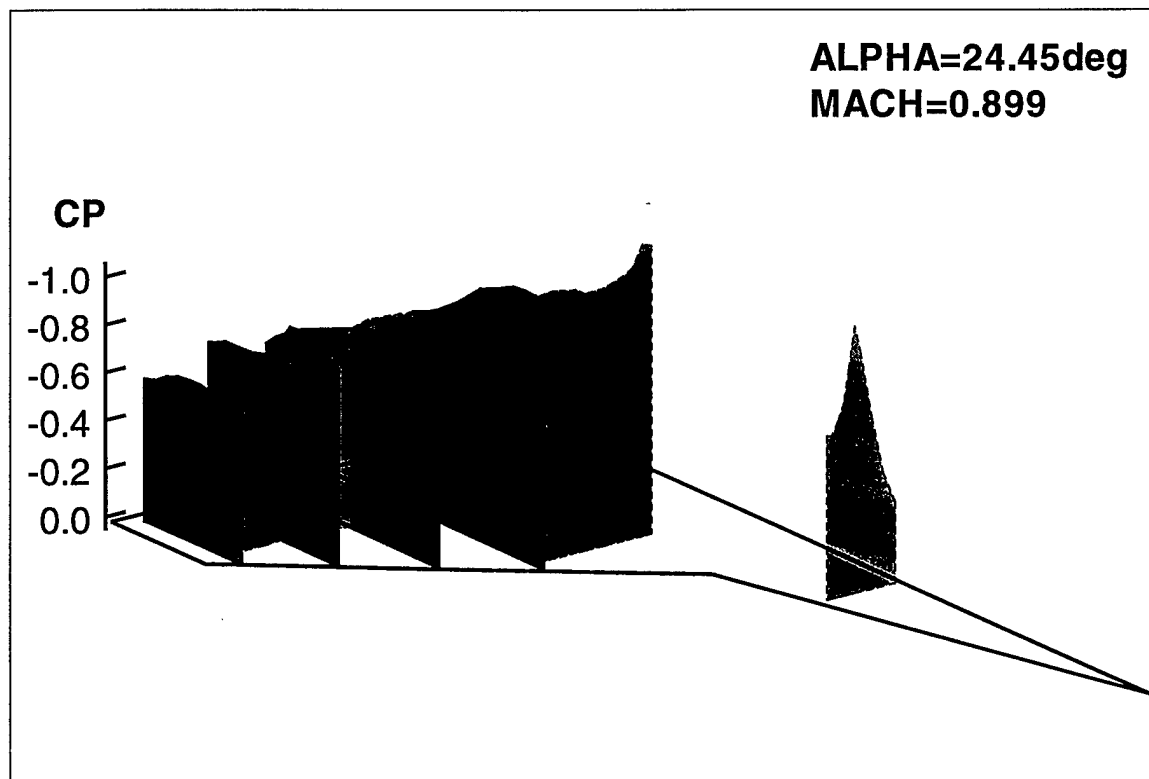


Sheet Position 8, Alpha = 23.7 deg
(Run ID = 64, Frame = -345)

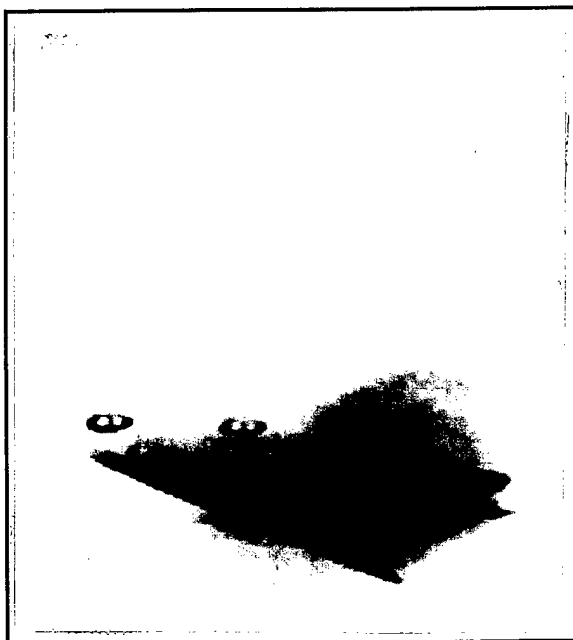


Sheet Position 9, Alpha = 23.4 deg
(Run ID = 69, Frame = -357)

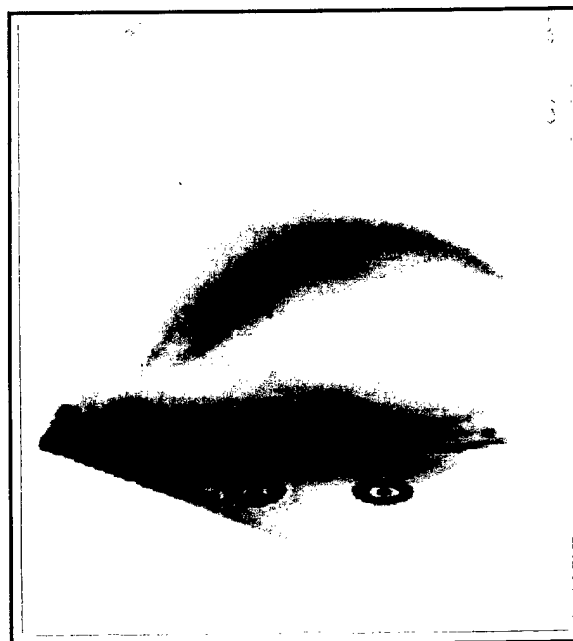
Figure 4.18 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 22.4 deg and 23.4 deg



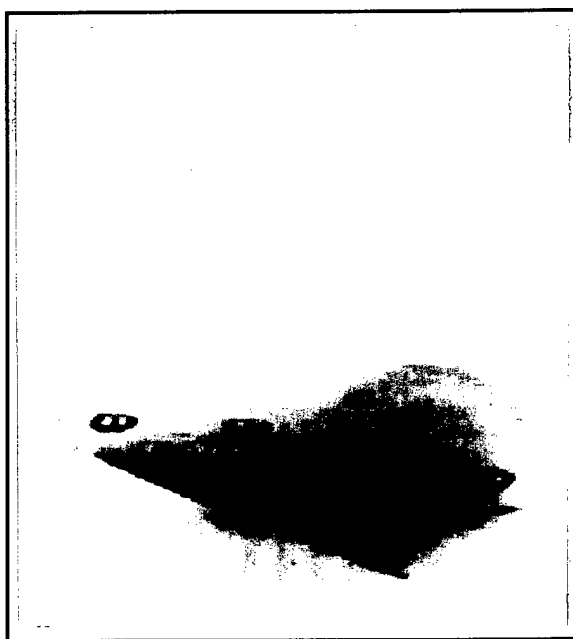
**Figure 4.19 - Steady Pressure Distributions at
Angles of 24.45 deg and 25.43 deg**



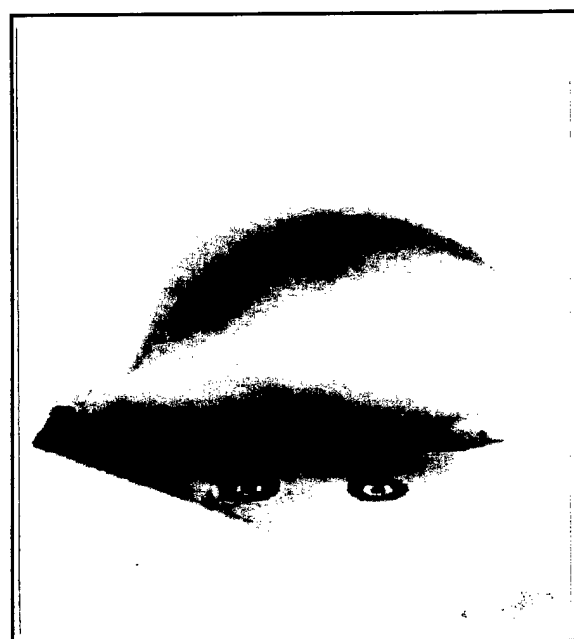
Sheet Position 8, Alpha = 24.7 deg
(Run ID = 64, Frame = -315)



Sheet Position 9, Alpha = 24.3 deg
(Run ID = 69, Frame = -330)

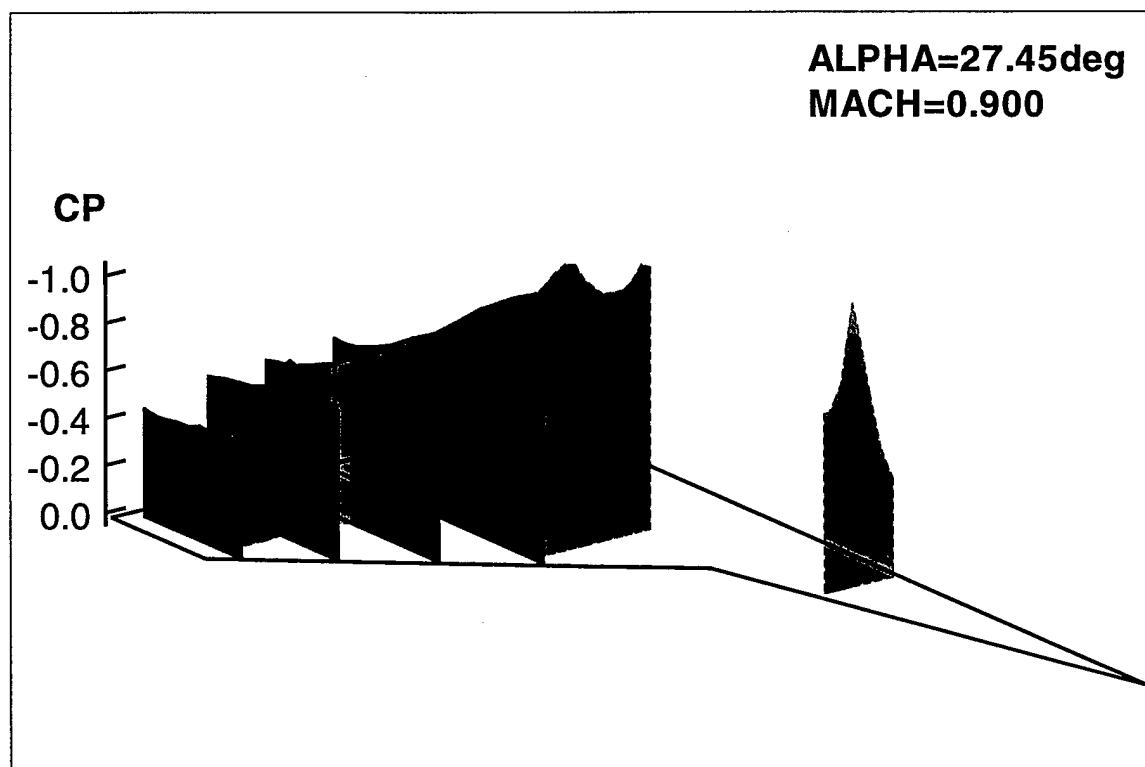
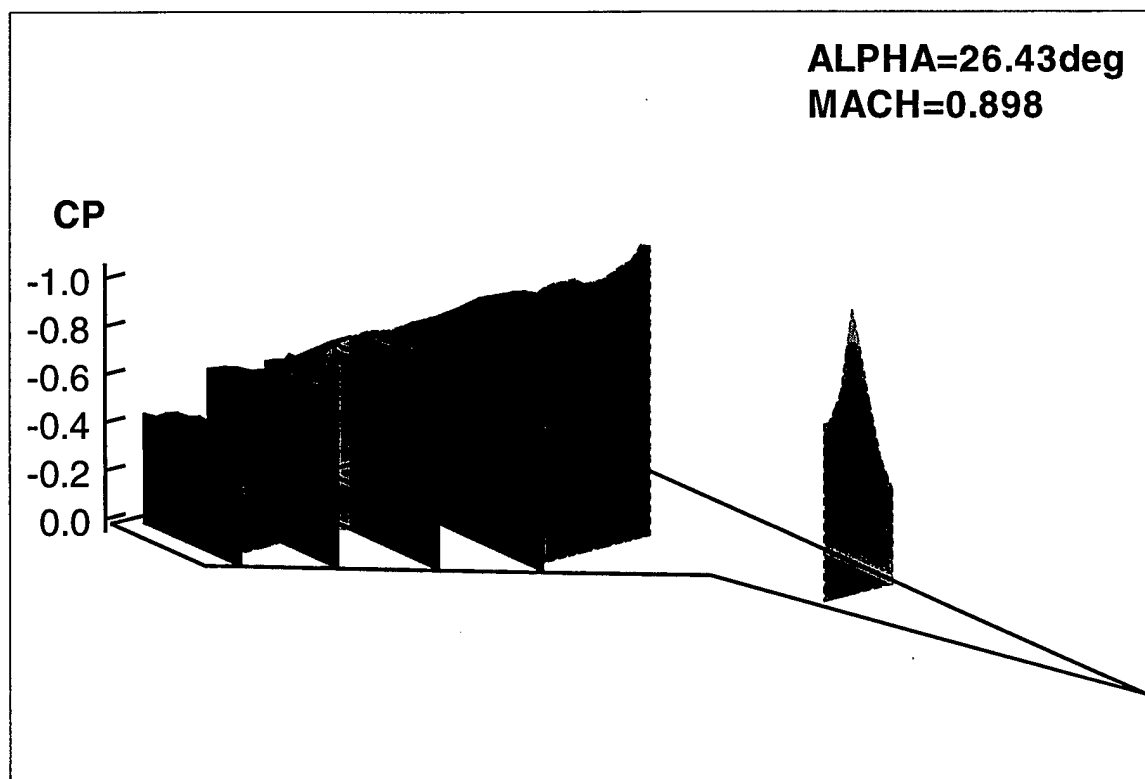


Sheet Position 8, Alpha = 25.7 deg
(Run ID = 64, Frame = -287)

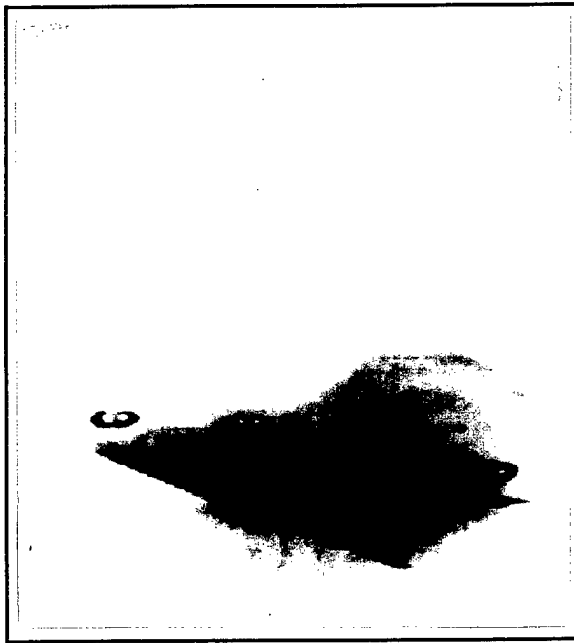


Sheet Position 9, Alpha = 25.4 deg
(Run ID = 69, Frame = -302)

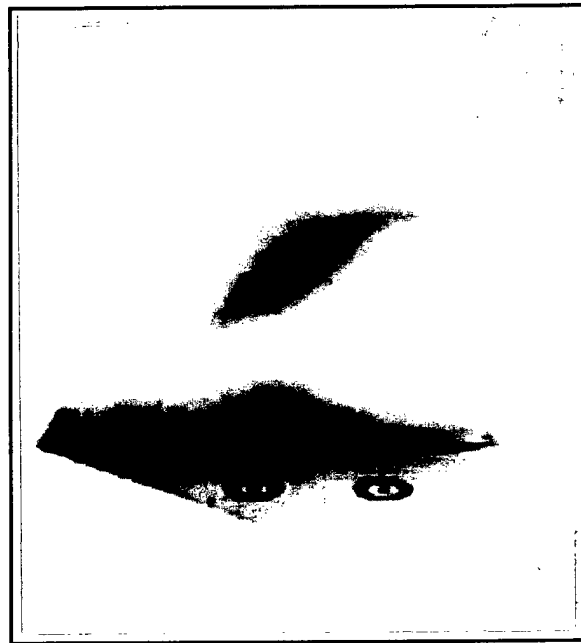
Figure 4.20 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 24.3 deg and 25.4 deg



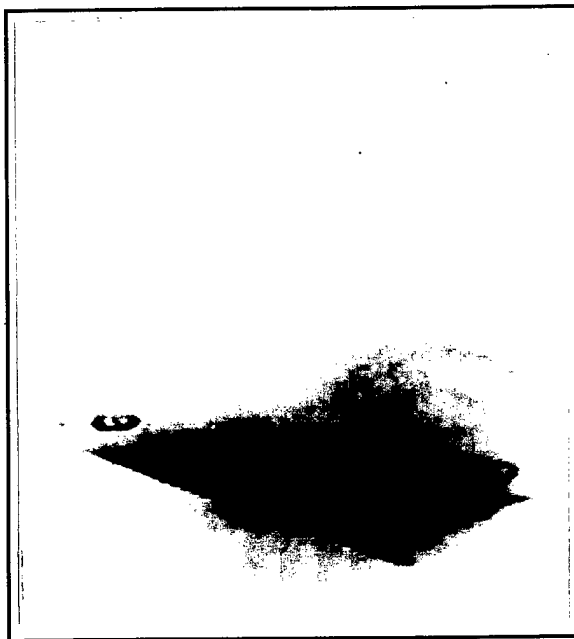
**Figure 4.21 - Steady Pressure Distributions at
Angles of 26.43 deg and 27.45 deg**



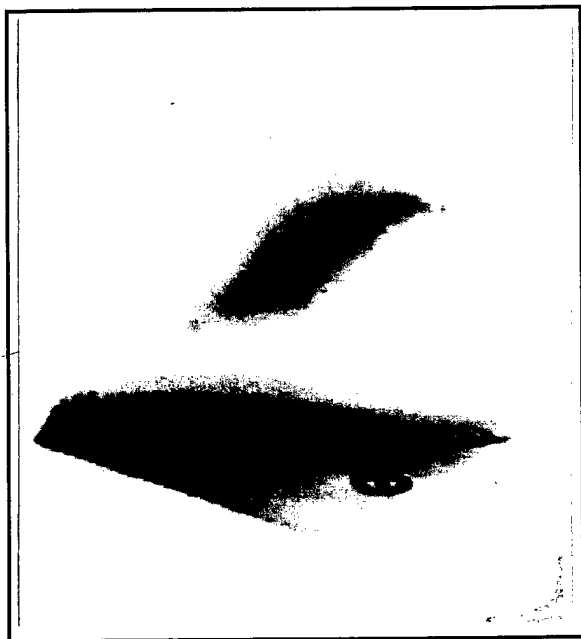
Sheet Position 8, Alpha = 26.9 deg
(Run ID = 64, Frame = -258)



Sheet Position 9, Alpha = 26.4 deg
(Run ID = 69, Frame = -274)

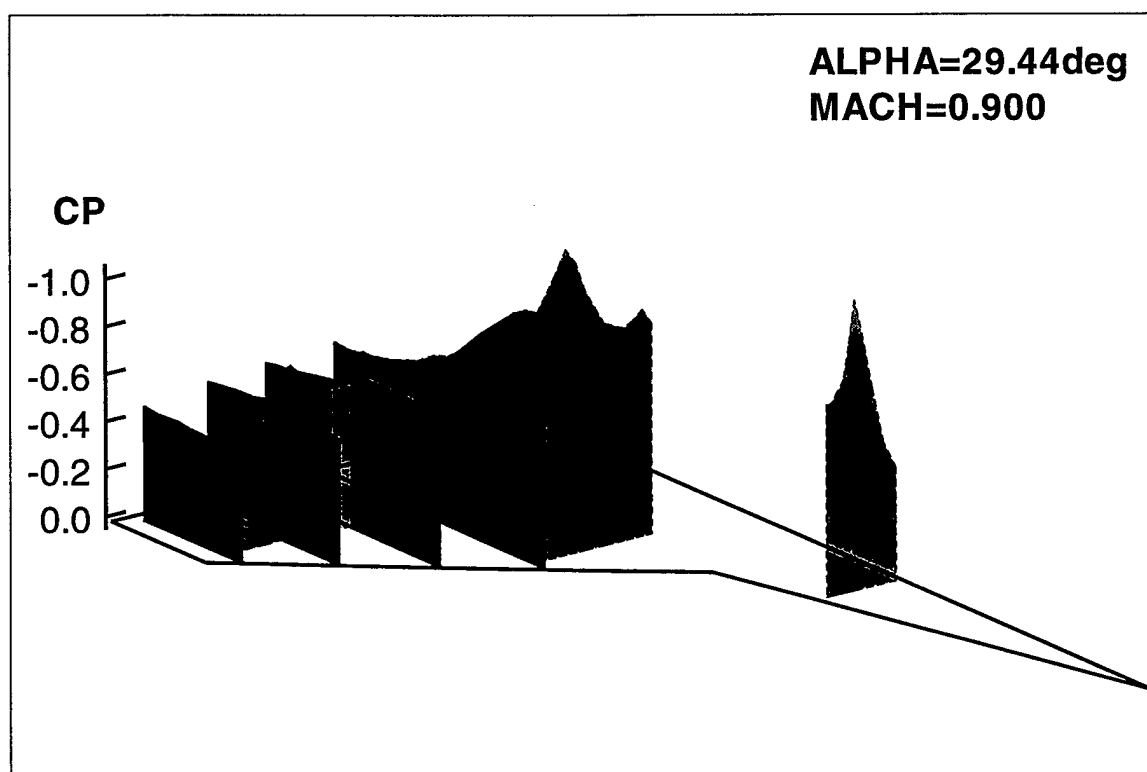
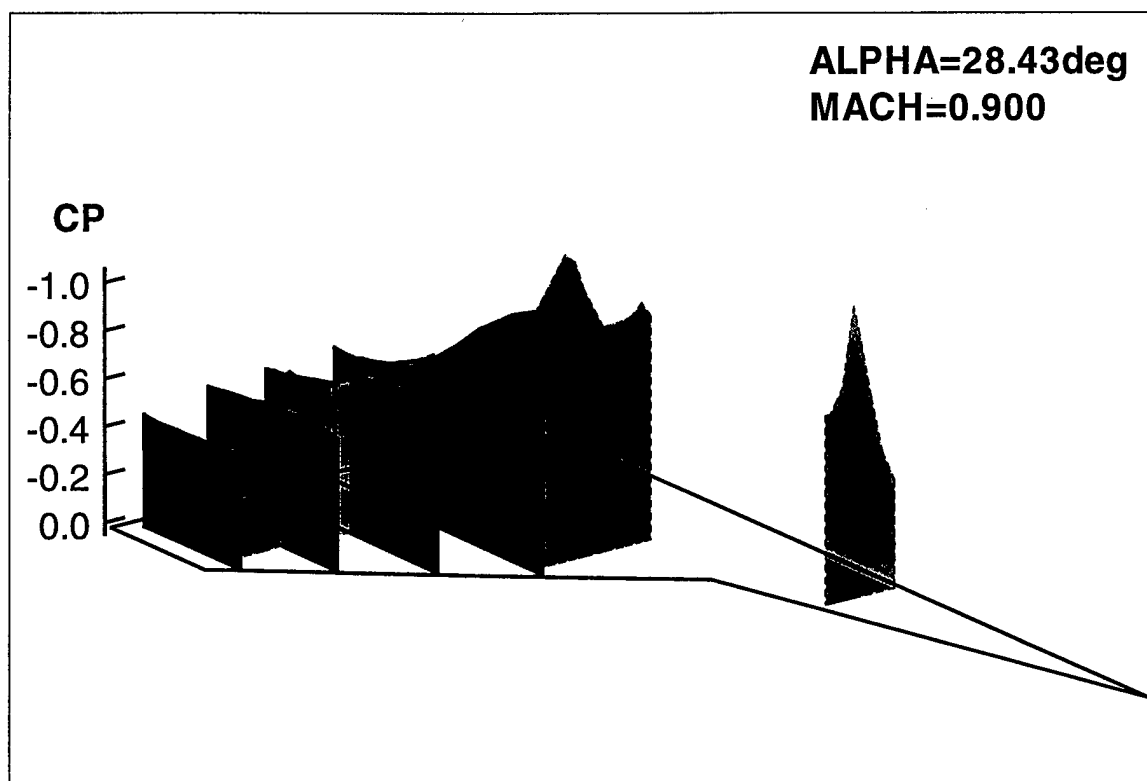


Sheet Position 8, Alpha = 27.4 deg
(Run ID = 64, Frame = -231)

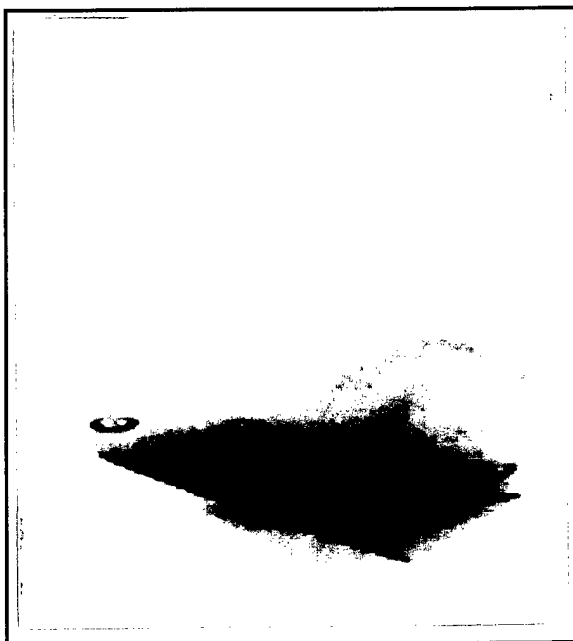


Sheet Position 9, Alpha = 27.7 deg
(Run ID = 69, Frame = -244)

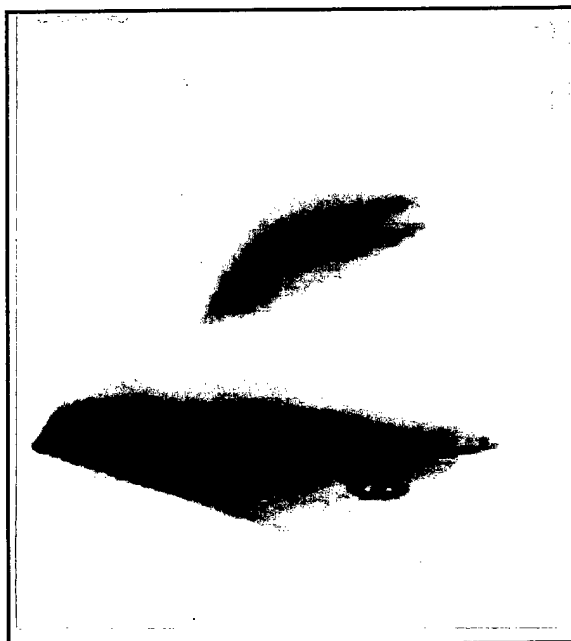
Figure 4.22 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 26.4 deg and 27.4 deg



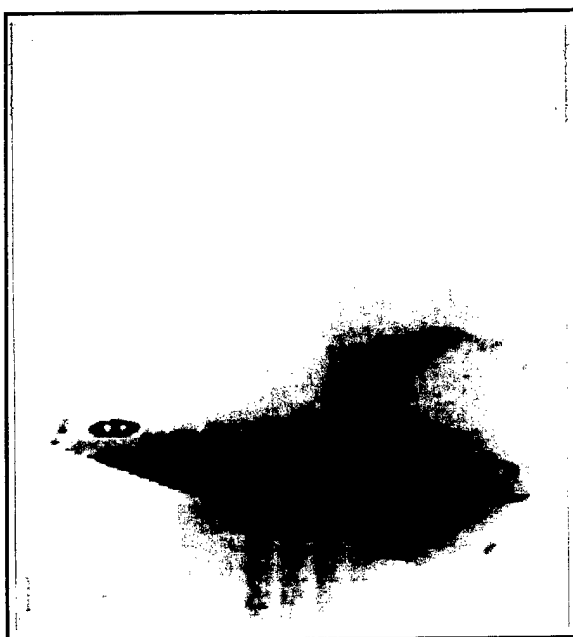
**Figure 4.23 - Steady Pressure Distributions at
Angles of 28.43 deg and 29.44 deg**



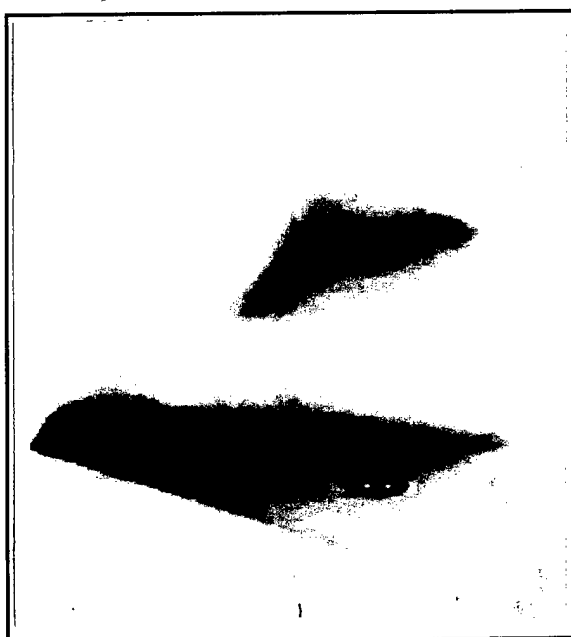
Sheet Position 8, Alpha = 28.6 deg
(Run ID = 64, Frame = -207)



Sheet Position 9, Alpha = 28.4 deg
(Run ID = 69, Frame = -217)

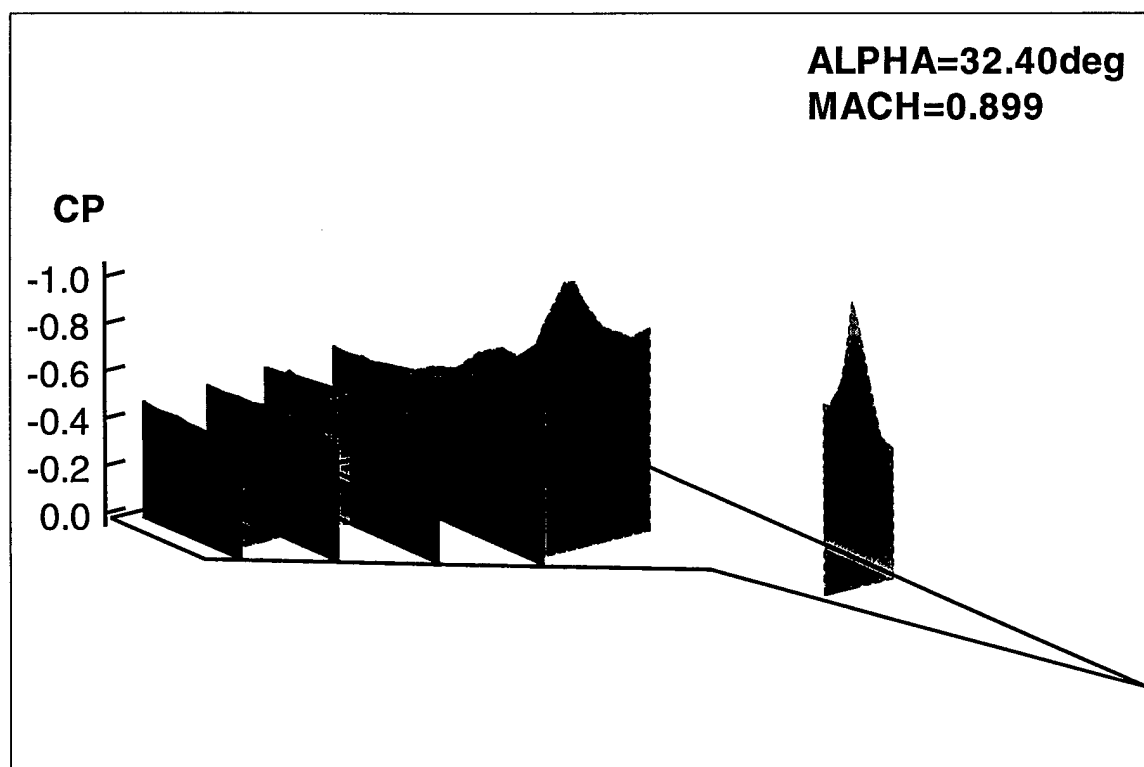
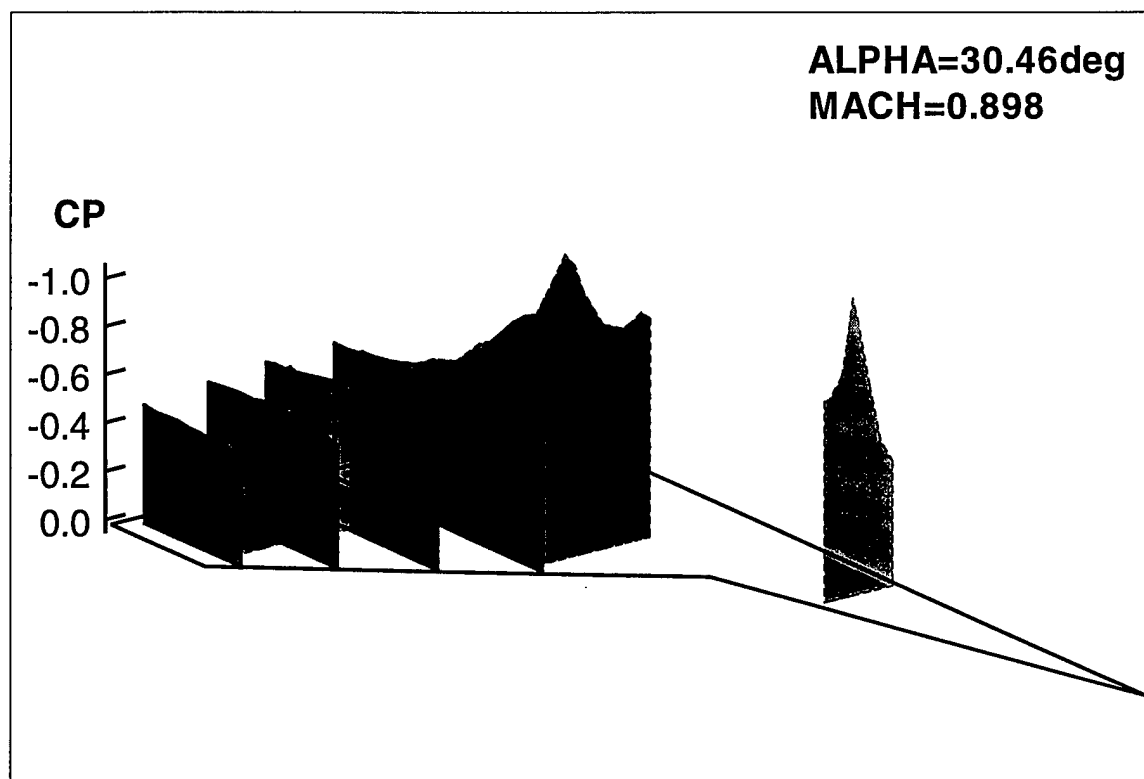


Sheet Position 8, Alpha = 29.4 deg
(Run ID = 64, Frame = -171)

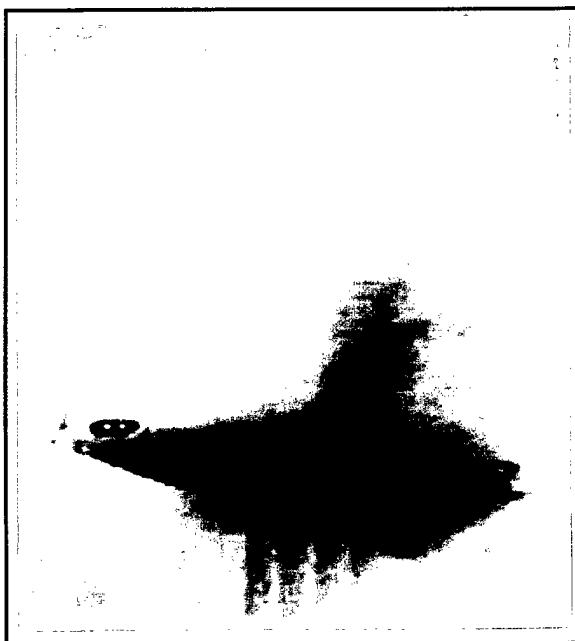


Sheet Position 9, Alpha = 29.2 deg
(Run ID = 69, Frame = -188)

Figure 4.24 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 28.4 deg and 29.2 deg



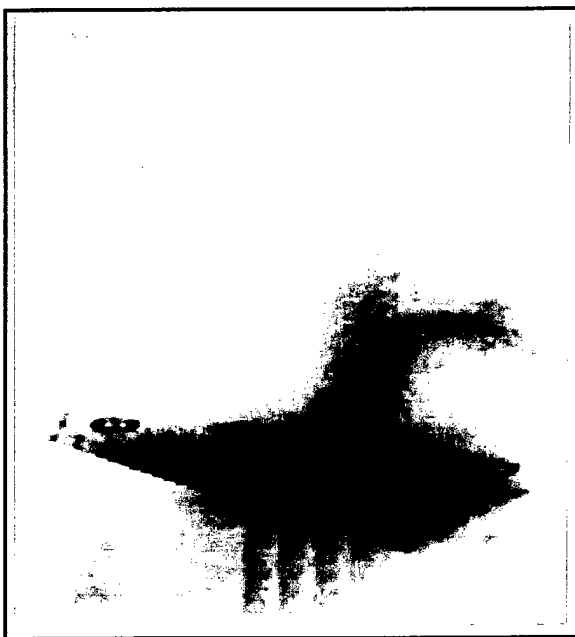
**Figure 4.25 - Steady Pressure Distributions at
Angles of 30.46 deg and 32.40 deg**



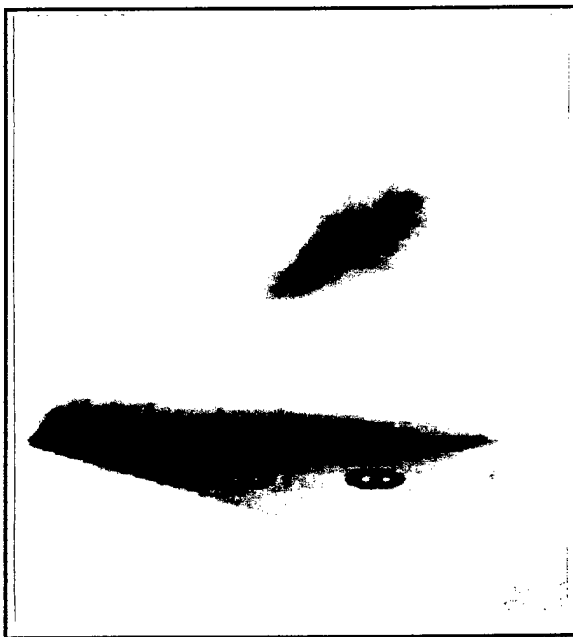
Sheet Position 8, Alpha = 30.6 deg
(Run ID = 64, Frame = -144)



Sheet Position 9, Alpha = 30.4 deg
(Run ID = 69, Frame = -160)

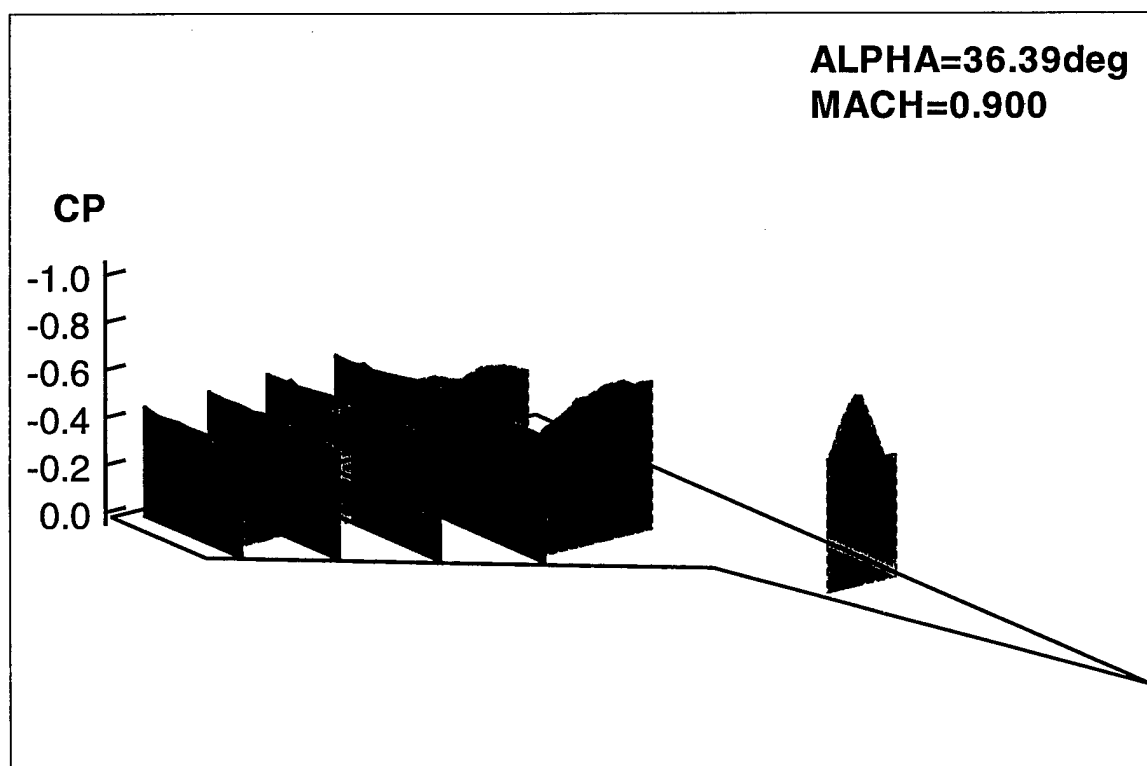
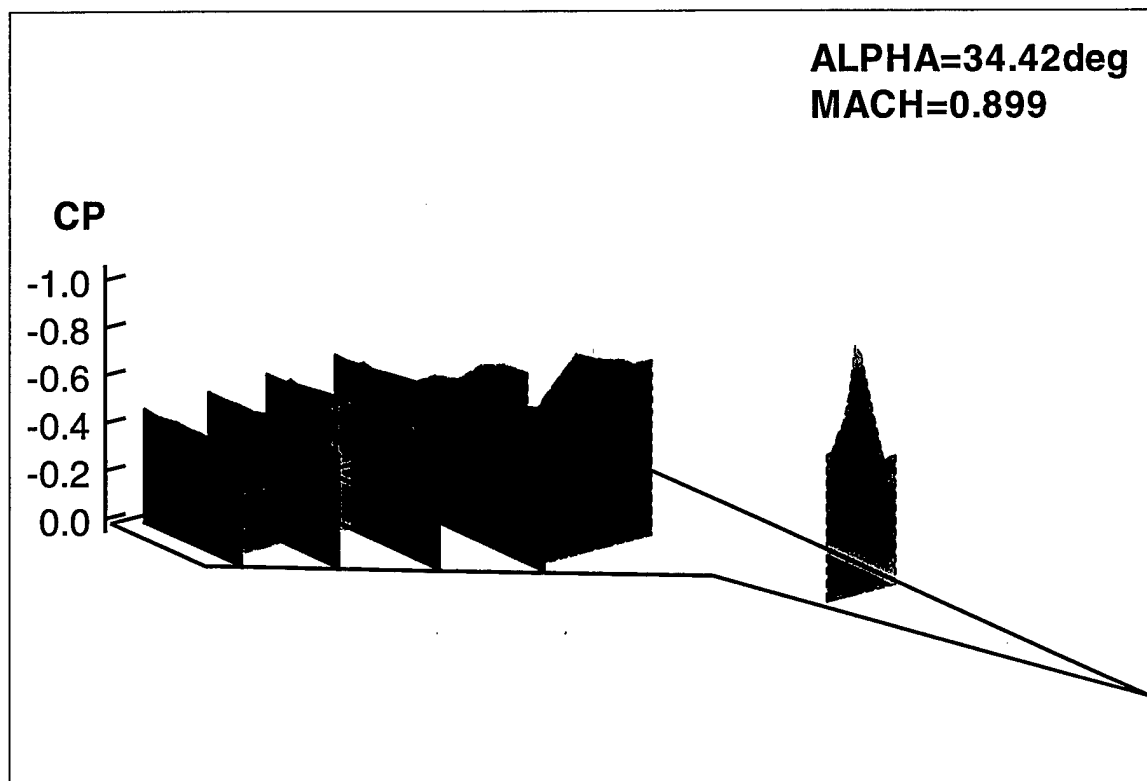


Sheet Position 8, Alpha = 32.3 deg
(Run ID = 64, Frame = -114)

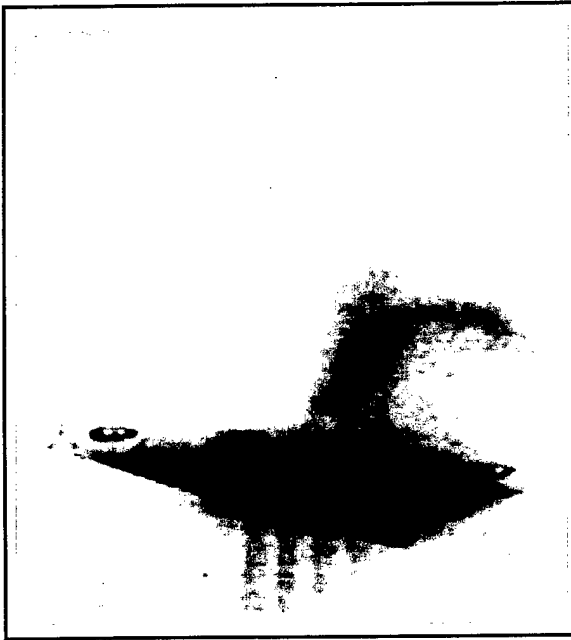


Sheet Position 9, Alpha = 32.3 deg
(Run ID = 69, Frame = -132)

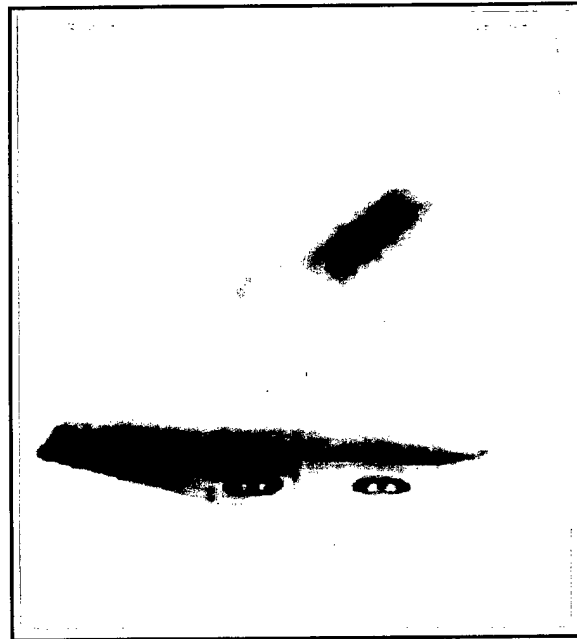
Figure 4.26 - High Speed Camera View of Spanwise Laser Light Sheet at M = 0.9, Alpha = 30.4 deg and 32.3 deg



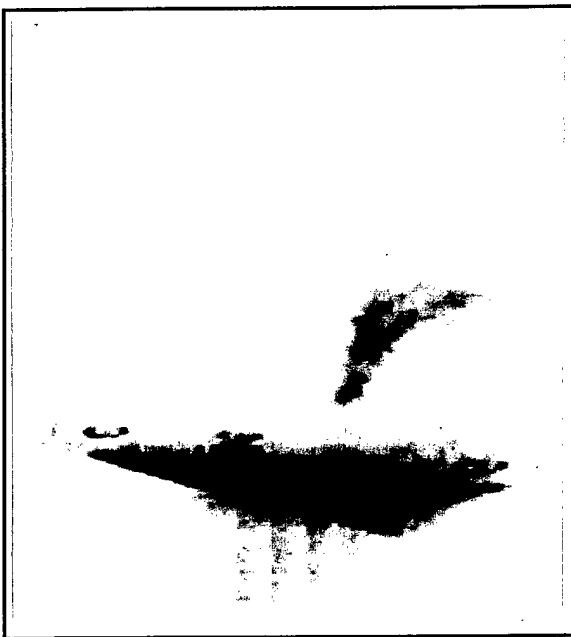
**Figure 4.27 - Steady Pressure Distributions at
Angles of 34.42 deg and 36.39 deg**



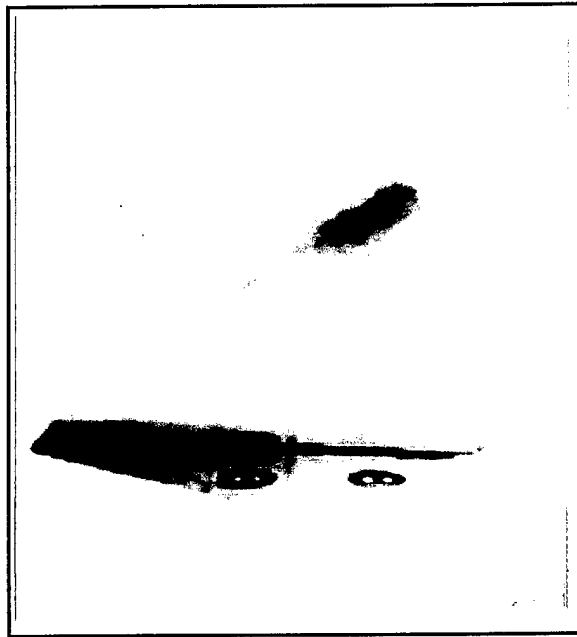
Sheet Position 8, Alpha = 34.3 deg
(Run ID = 64, Frame = -63)



Sheet Position 9, Alpha = 34.0 deg
(Run ID = 69, Frame = -75)



Sheet Position 8, Alpha = 32.3 deg
(Run ID = 64, Frame = -2)



Sheet Position 9, Alpha = 32.3 deg
(Run ID = 69, Frame = -21)

Figure 4.28 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.9$, Alpha = 34.0 deg and 36.0 deg

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3.0 SIDE VIEW CAMERA LOW SPEED VIDEO FLOW VISUALIZATION FOR THE CLEAN WING AT $M = 0.9$, $\alpha = 6$ DEG TO 34 DEG

Individual frames from the side view camera recordings are presented in this section for three chordwise sheet positions, 1, 3, and 14, as shown in Figure 5, below. In addition, several frames are presented that were obtained during a rotating sweep of the light sheet from Position 8 toward the wing tip, as also shown in Figure 5. These data are taken during a slow incidence sweep for which the data were recorded only on VHS tape at the conventional frame rate of 50 frames per second. The four sheet position data frames were selected to match and complement the incidence values shown in Figures 4.01 through 4.28, and are grouped together in each of the following Figures 6.01 through 6.31. Additional angles were selected between 10 deg and 11 deg in the vicinity of the onset of shock-induced trailing edge separation.

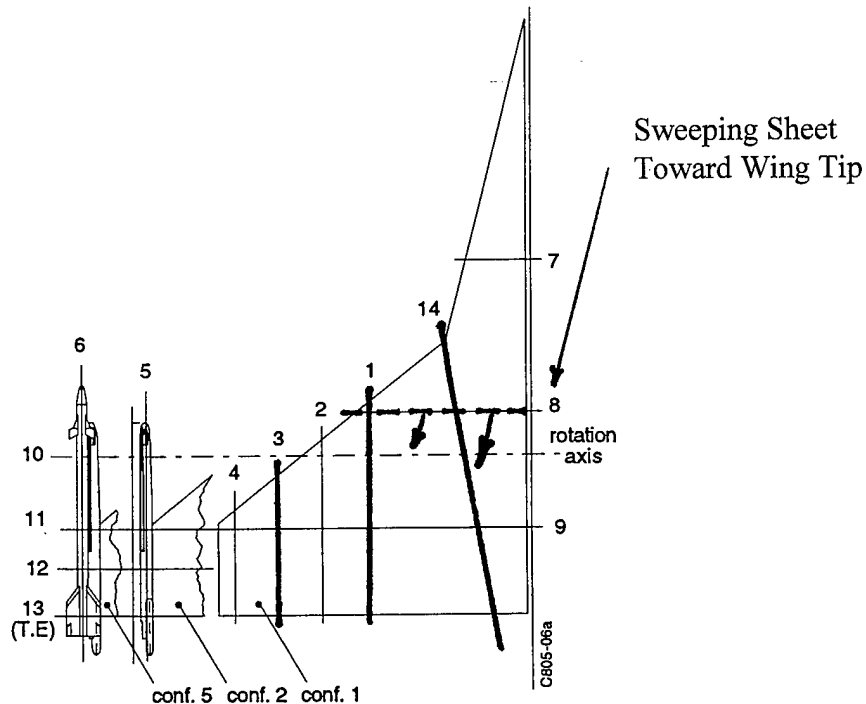
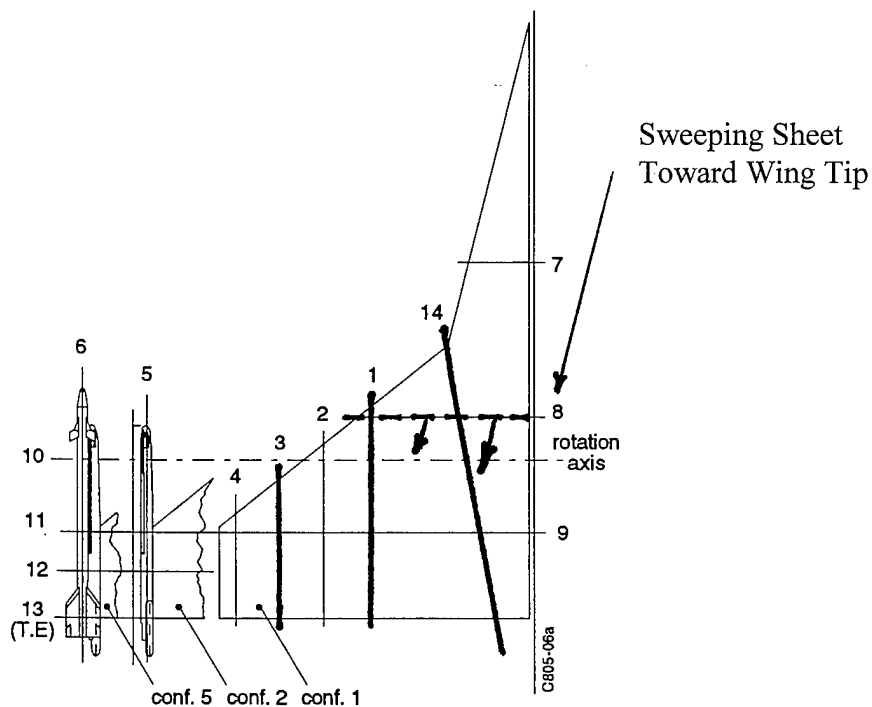
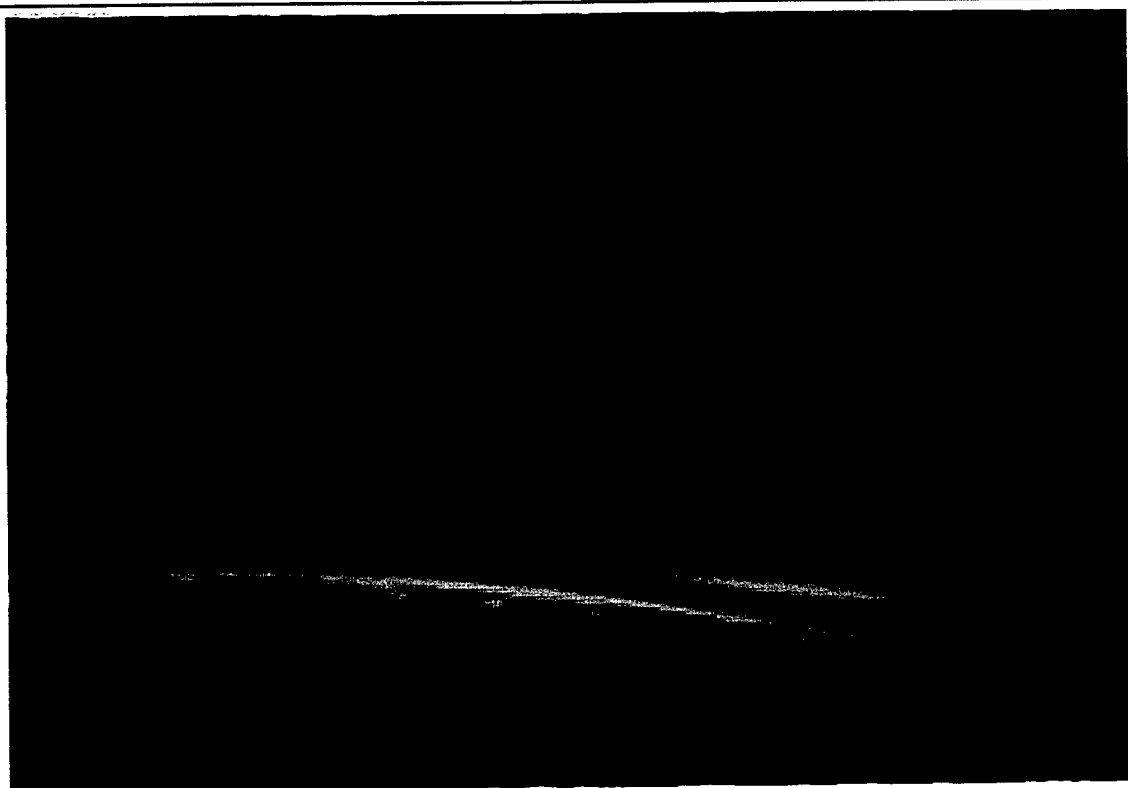


Figure 5 - Flow Visualization Sheet Locations for Figures 6, Clean Wing, $M = 0.9$, $\alpha = 6$ deg to 34 deg

Individual frames from the side view camera recordings are presented in this section for three chordwise sheet positions, 1, 3, and 14, as shown in Figure 5, below. In addition, several frames are presented that were obtained during a rotating sweep of the light sheet from Position 8 toward the wing tip, as also shown in Figure 5. These data are taken during a slow incidence sweep for which the data were recorded only on VHS tape at the conventional frame rate of 50 frames per second. The four sheet position data frames were selected to match and complement the incidence values shown in Figures 4.01 through 4.28, and are grouped together in each of the following Figures 6.01 through 6.31. Additional angles were selected between 10 deg and 11 deg in the vicinity of the onset of shock-induced trailing edge separation.



53



Sheet Position 1, Alpha = 5.46 deg



Sheet Position 3, Alpha = 5.43 deg

**Figure 6.01 - Side View Camera of Streamwise Laser Light Sheet
at Various Positions, $M = 0.9$, $\alpha = 5.45^\circ$**

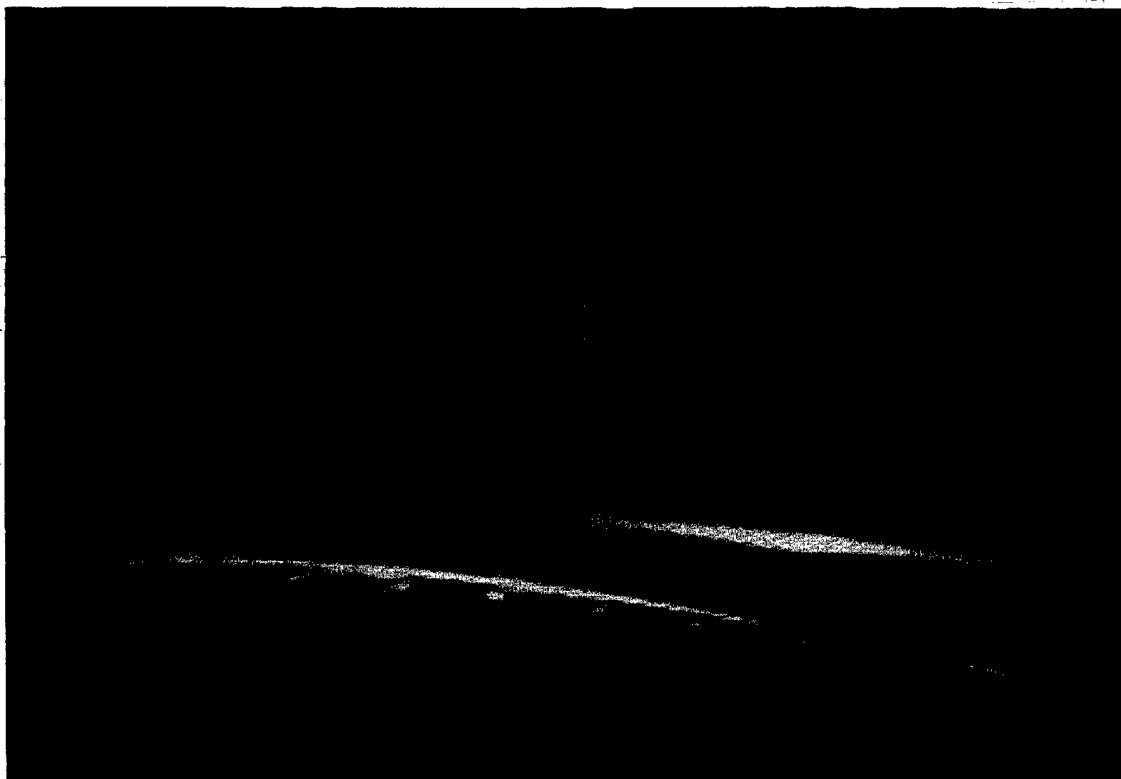


Sheet Position 14, Alpha = 5.44 deg

NO DATA

Sweeping Sheet, Alpha = 5.44 deg

Figure 6.01 - (Concluded)

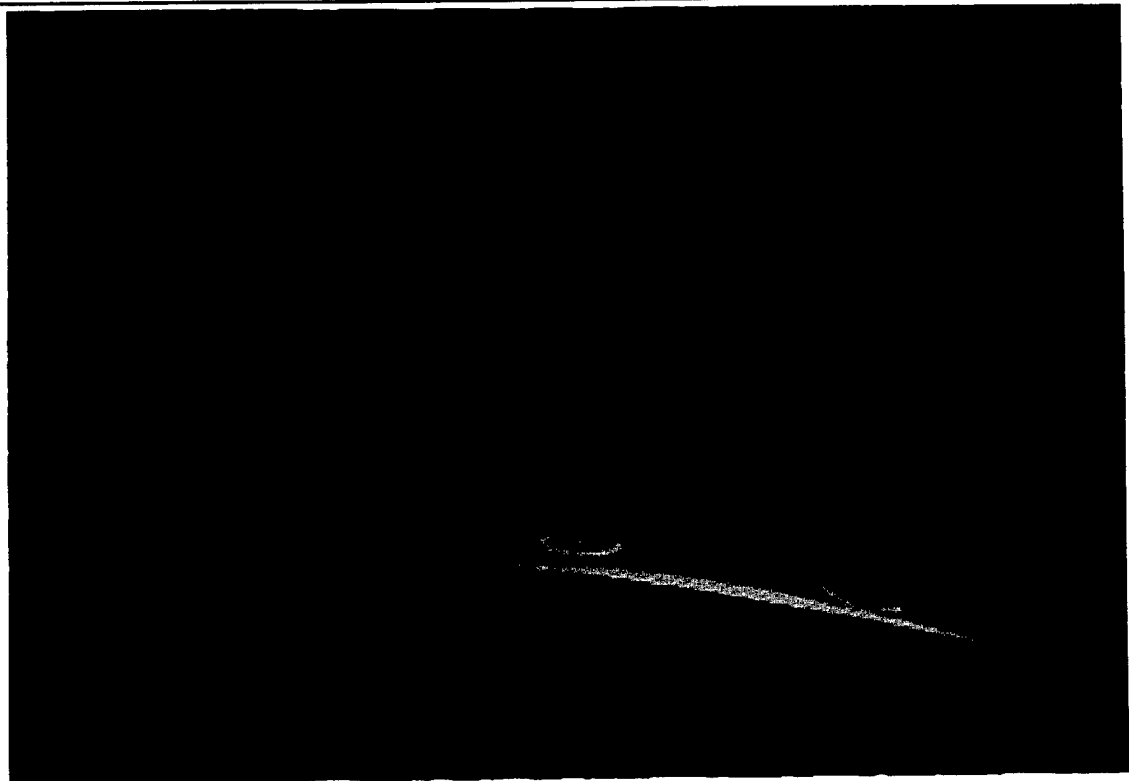


Sheet Position 1, Alpha = 6.52 deg



Sheet Position 3, Alpha = 6.52 deg

Figure 6.02 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 6.52$ deg

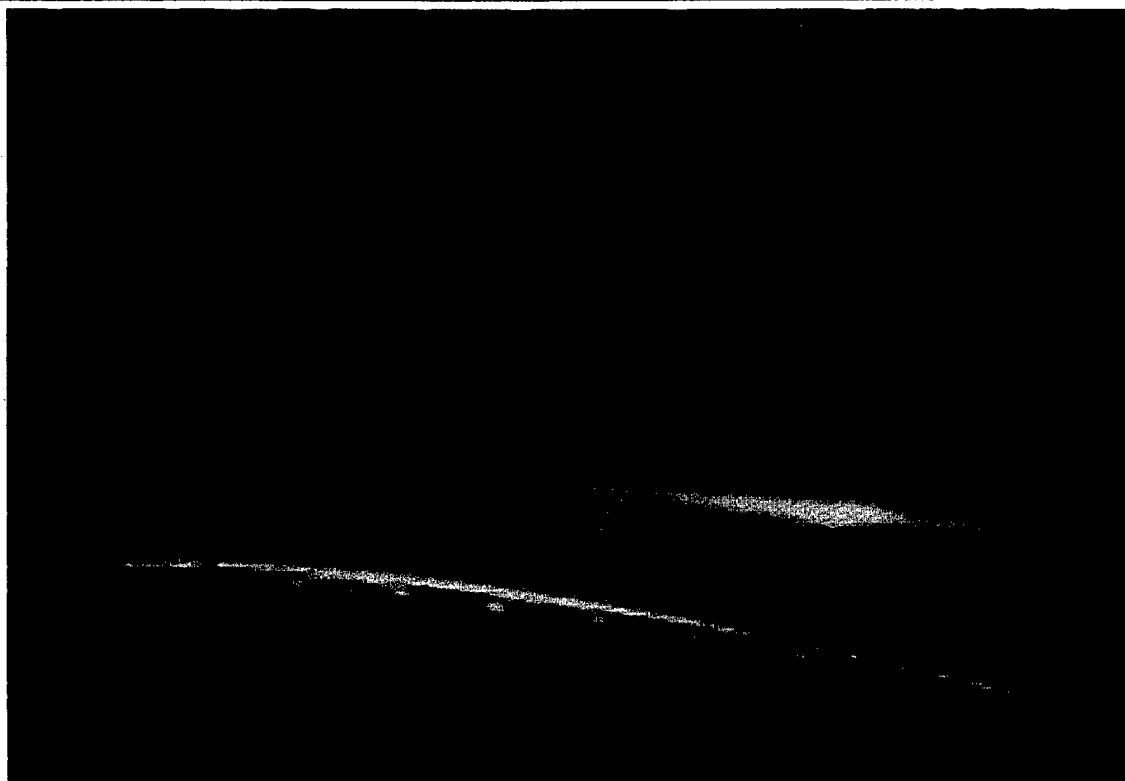


Sheet Position 14, Alpha = 6.48 deg

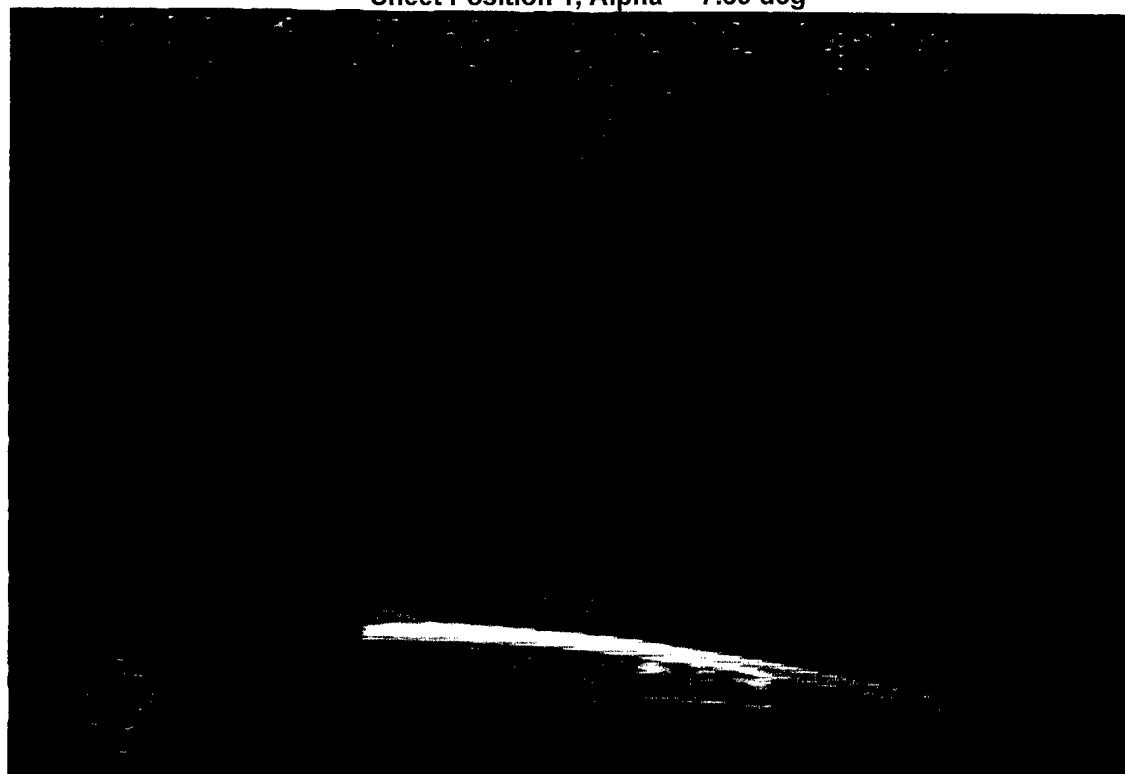
NO DATA

Sweeping Sheet, Alpha = 6.48 deg

Figure 6.02 - (Concluded)

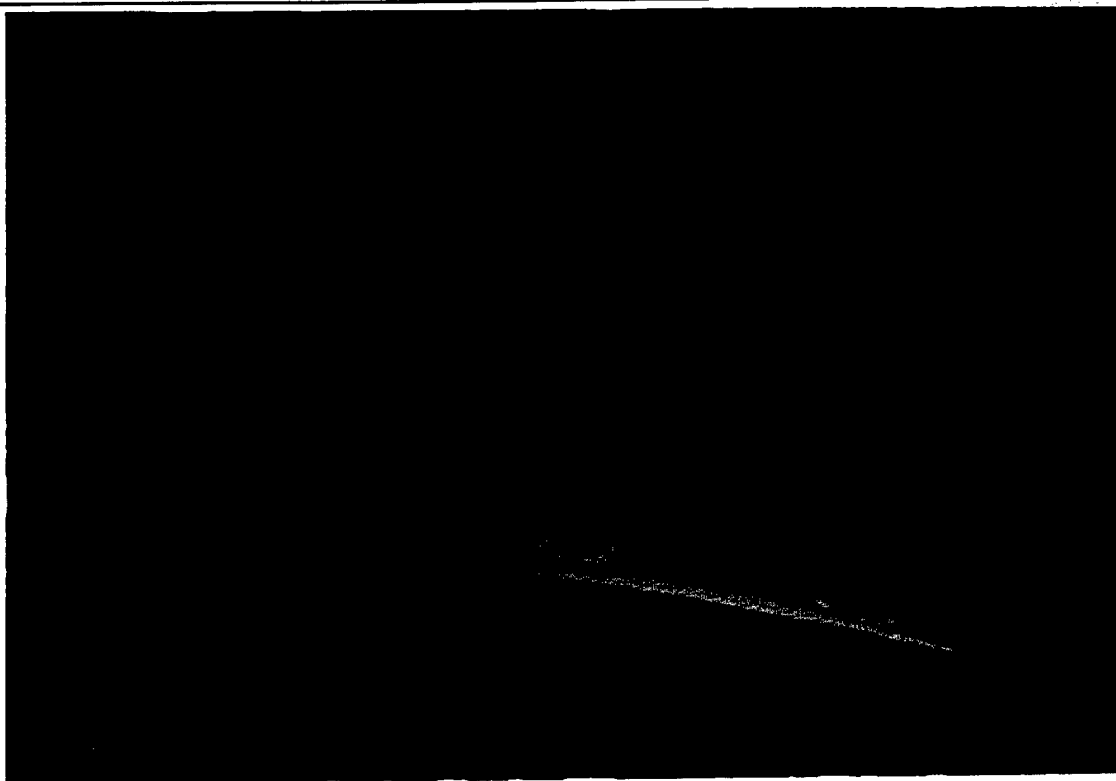


Sheet Position 1, $\alpha = 7.59^\circ$



Sheet Position 3, $\alpha = 7.64^\circ$

Figure 6.03 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 7.62^\circ$

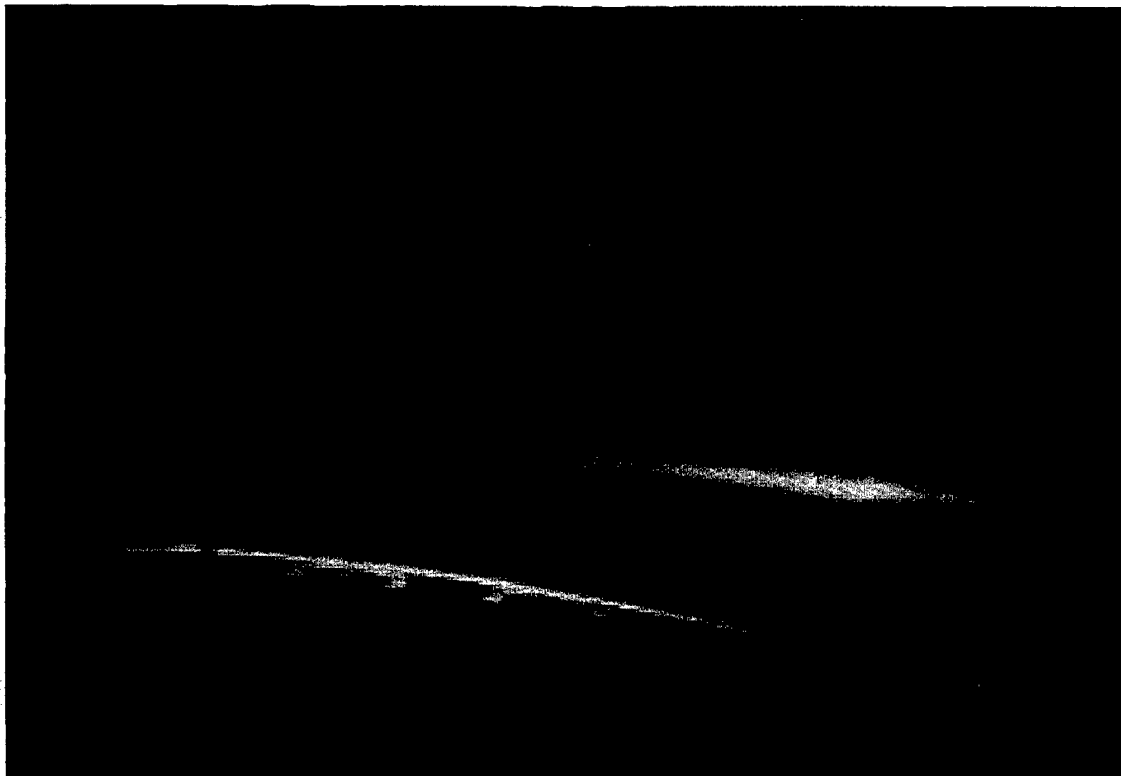


Sheet Position 14, Alpha = 7.54 deg

NO DATA

Sweeping Sheet, Alpha = 7.54 deg

Figure 6.03 - (Concluded)

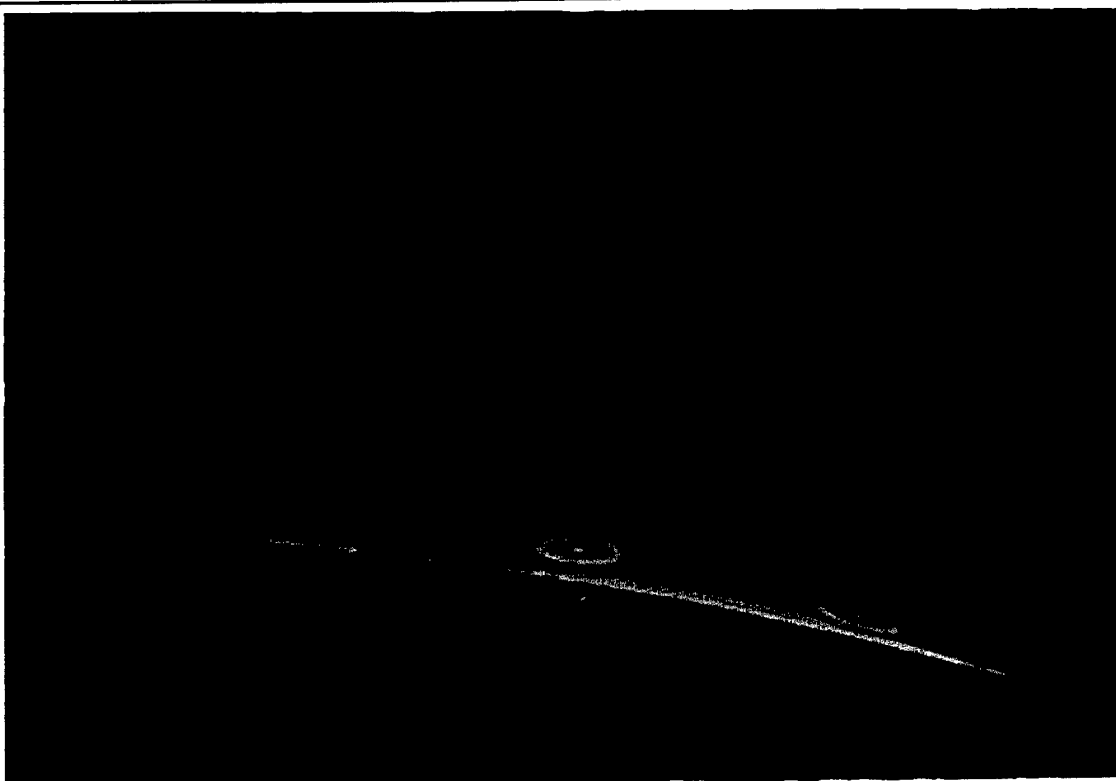


Sheet Position 1, $\alpha = 8.64$ deg



Sheet Position 3, $\alpha = 8.50$ deg

Figure 6.04 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 8.57$ deg

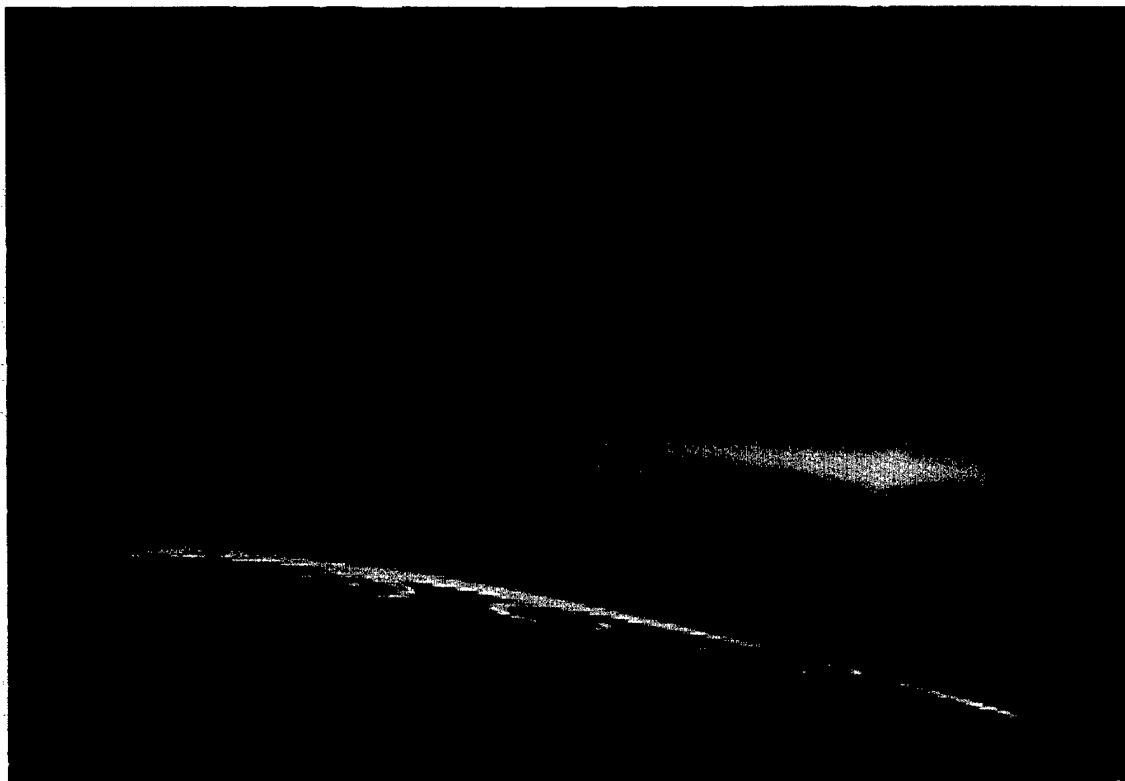


Sheet Position 14, Alpha = 8.56 deg

NO DATA

Sweeping Sheet, Alpha = 8.56 deg

Figure 6.04 - (Concluded)

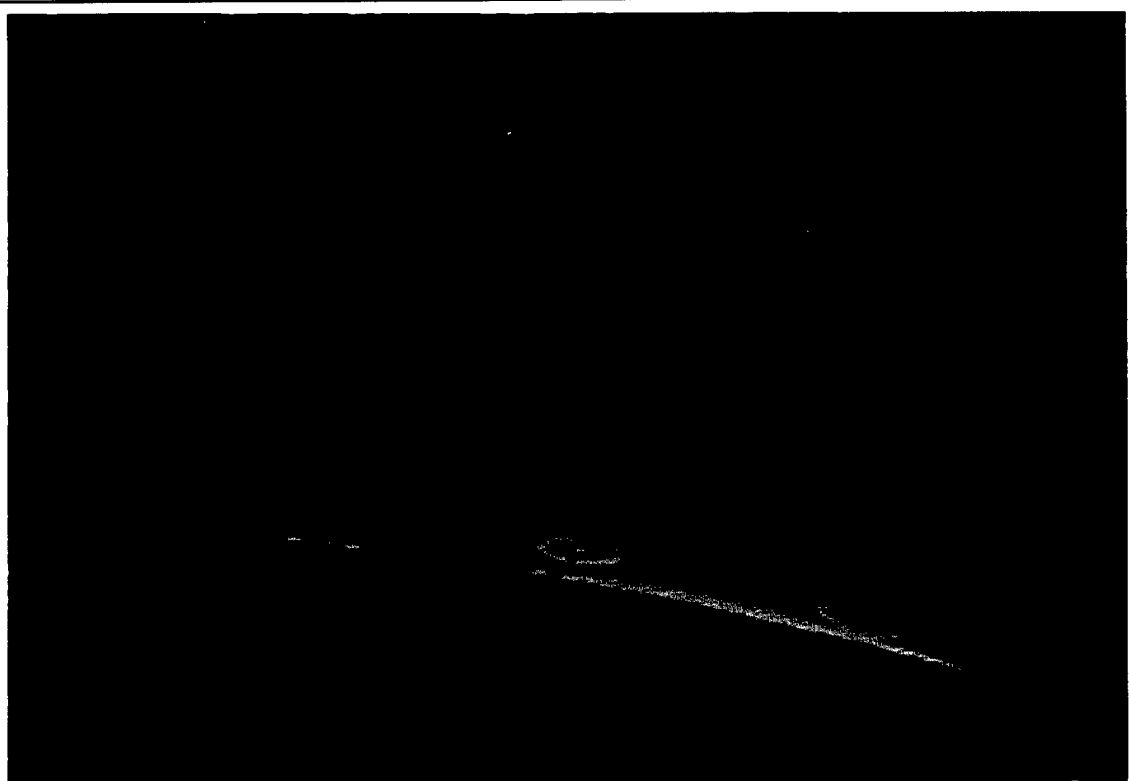


Sheet Position 1, Alpha = 9.56 deg



Sheet Position 3, Alpha = 9.55 deg

Figure 6.05 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 9.56$ deg

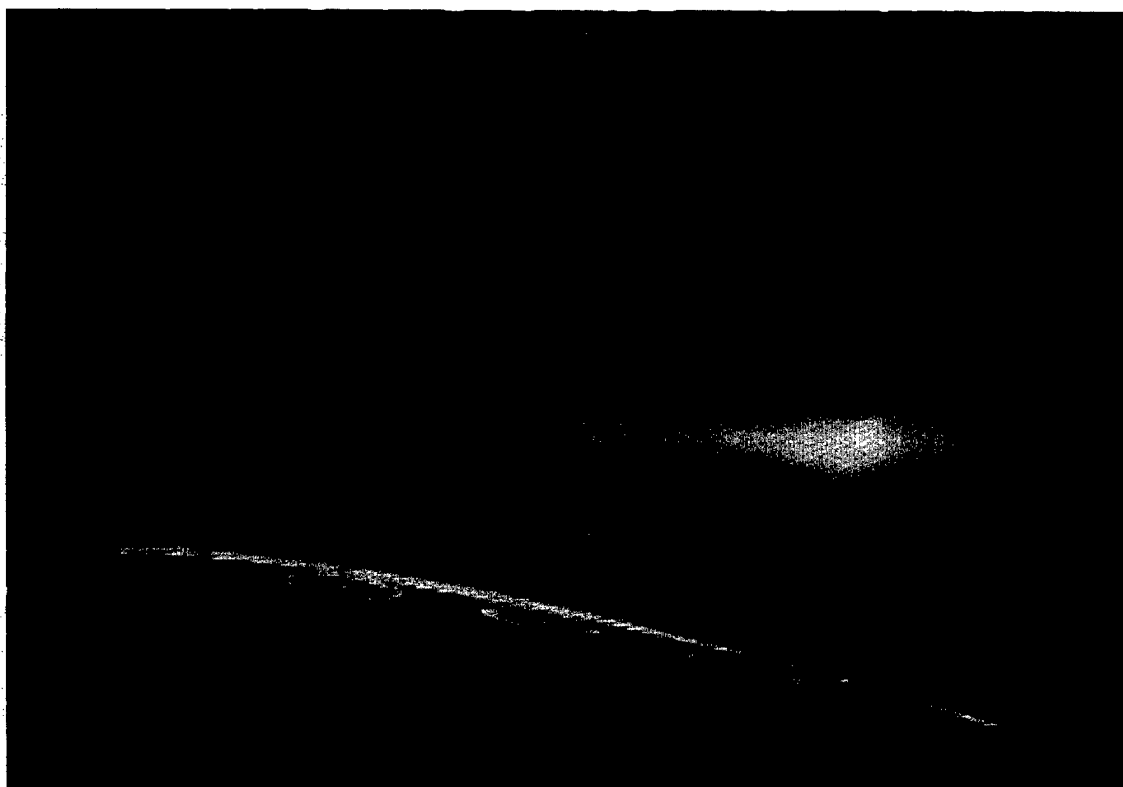


Sheet Position 14, Alpha = 9.49 deg

NO DATA

Sweeping Sheet, Alpha = 9.49 deg

Figure 6.05 - (Concluded)

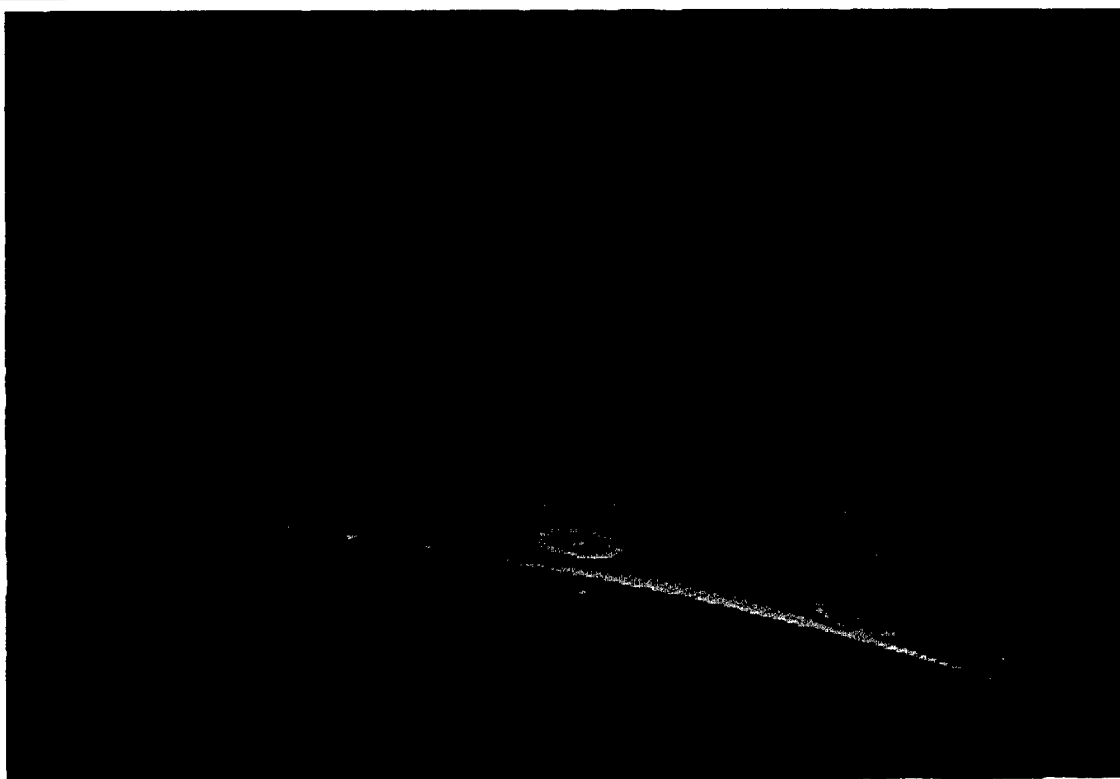


Sheet Position 1, Alpha = 10.30 deg



Sheet Position 3, Alpha = 10.32 deg

**Figure 6.06 - Side View Camera of Streamwise Laser Light Sheet
at Various Positions, $M = 0.9$, Alpha = 10.31 deg**



Sheet Position 14, $\alpha = 10.41$ deg

NO DATA

Sweeping Sheet, $\alpha = 10.41$ deg

Figure 6.06 - (Concluded)

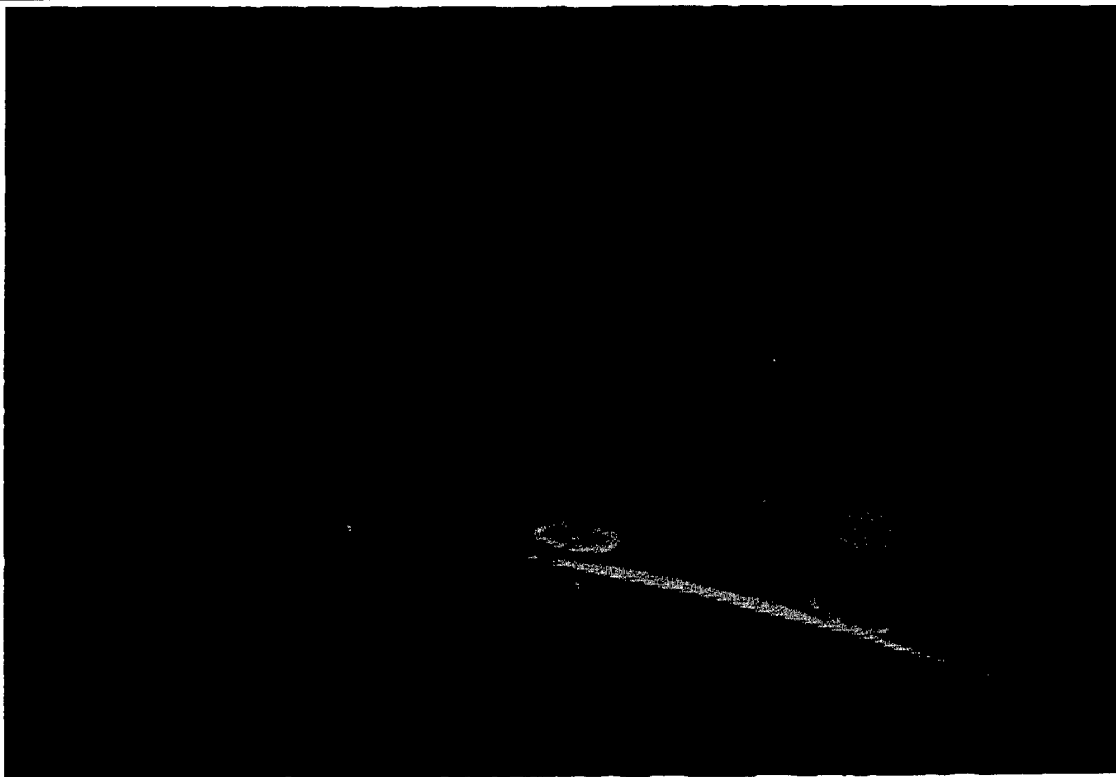
NO DATA

Sheet Position 1, Alpha = 10.67 deg



Sheet Position 3, Alpha = 10.67 deg

**Figure 6.07 - Side View Camera of Streamwise Laser Light Sheet
at Various Positions, $M = 0.9$, $\alpha = 10.67$ deg**

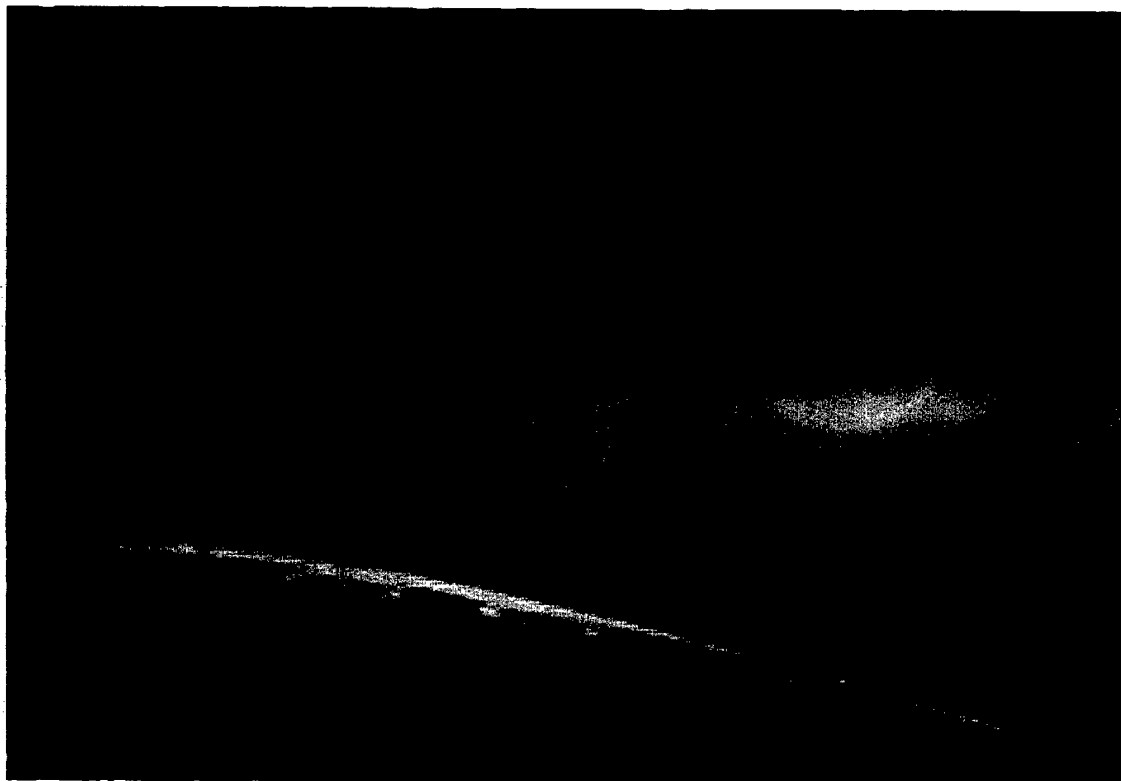


Sheet Position 14, $\alpha = 10.77^\circ$

NO DATA

Sweeping Sheet, $\alpha = 10.77^\circ$

Figure 6.07 - (Concluded)

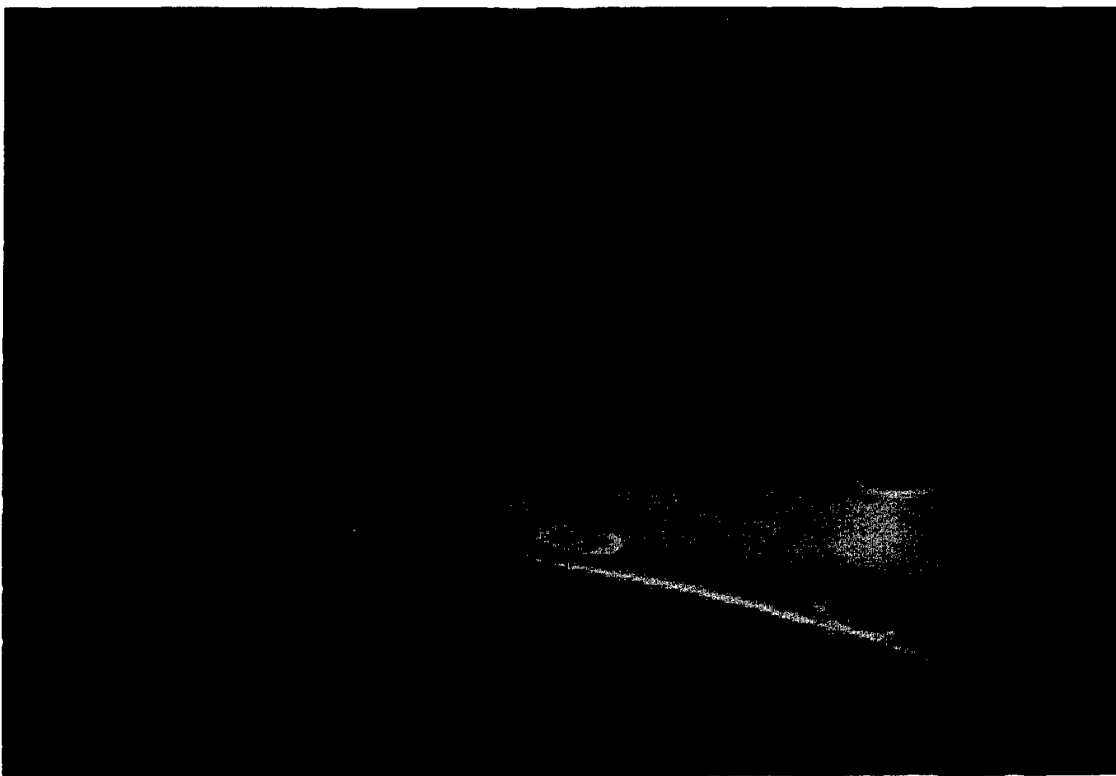


Sheet Position 1, Alpha = 10.85 deg



Sheet Position 3, Alpha = 10.86 deg

**Figure 6.08 - Side View Camera of Streamwise Laser Light Sheet
at Various Positions, $M = 0.9$, Alpha = 10.86 deg**



Sheet Position 14, Alpha = 10.93 deg

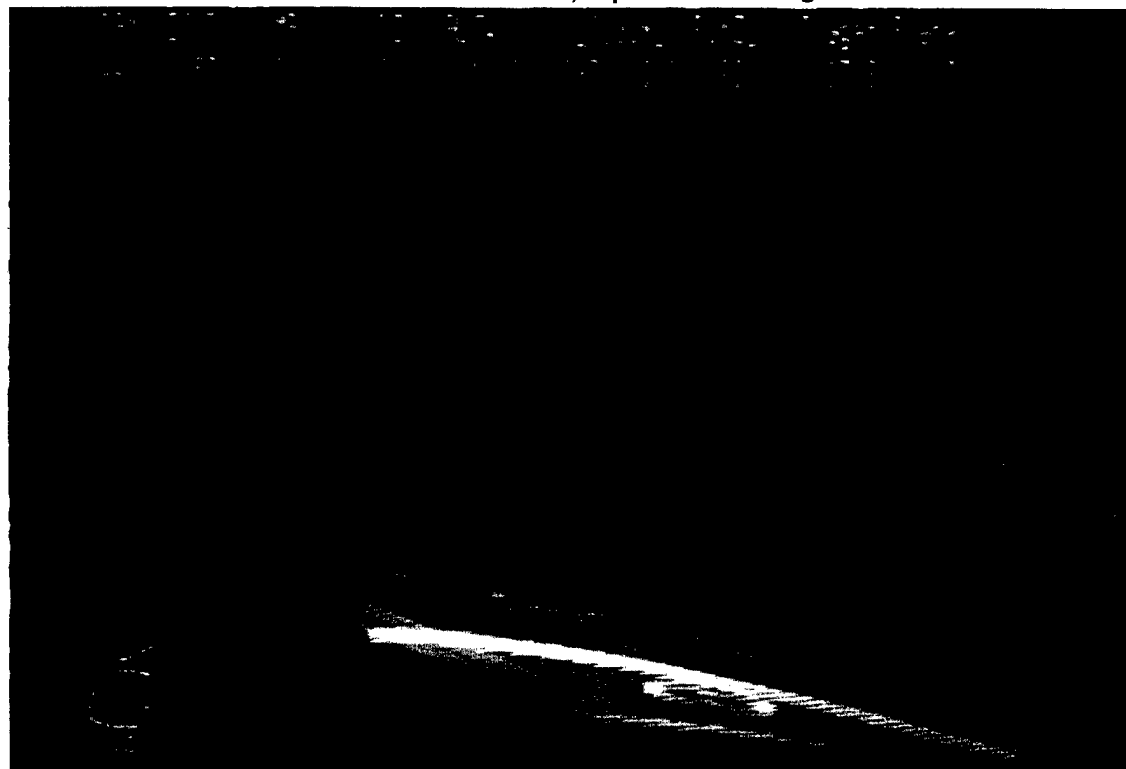
NO DATA

Sweeping Sheet, Alpha = 10.93 deg

Figure 6.08 - (Concluded)

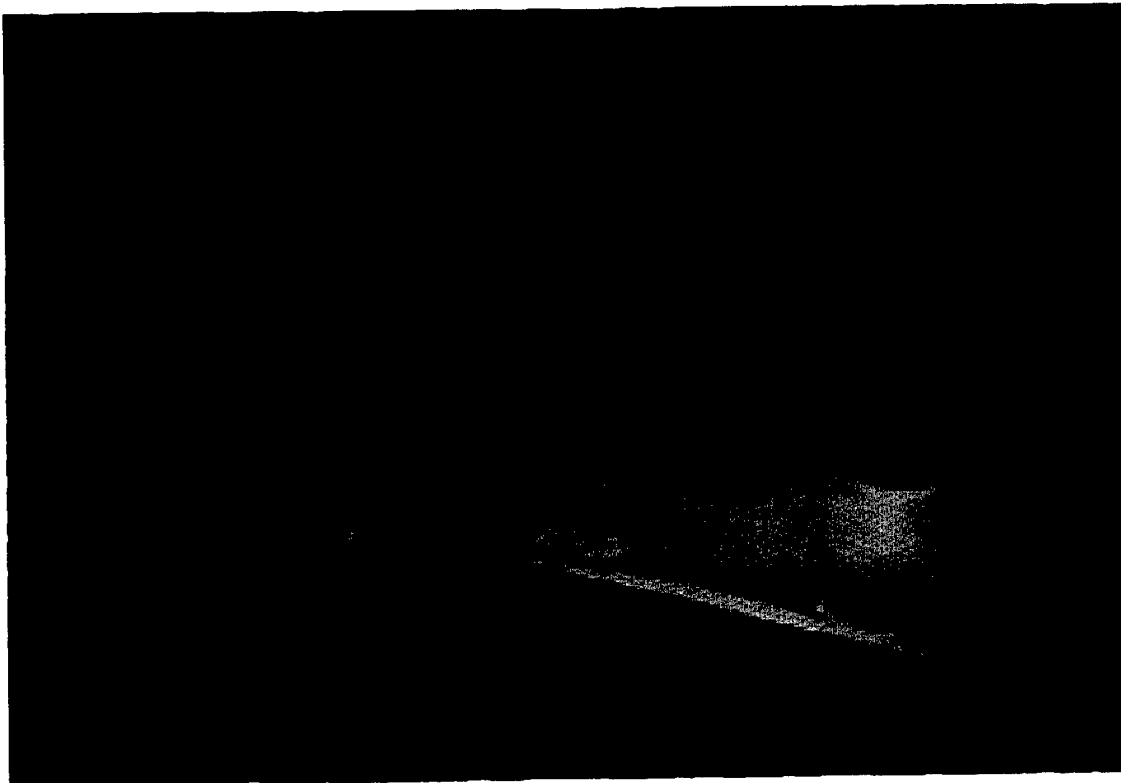


Sheet Position 1, Alpha = 11.04 deg



Sheet Position 3, Alpha = 11.03 deg

**Figure 6.09 - Side View Camera of Streamwise Laser Light Sheet
at Various Positions, $M = 0.9$, $\alpha = 11.04$ deg**

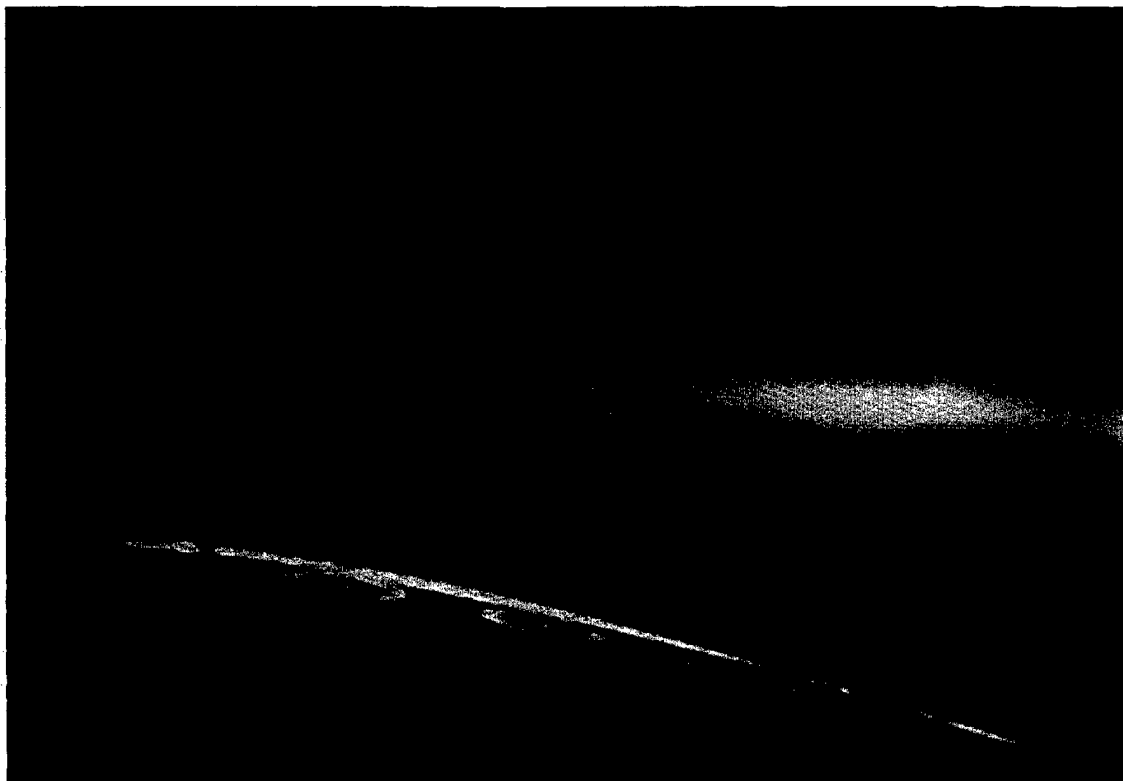


Sheet Position 14, $\alpha = 11.15^\circ$

NO DATA

Sweeping Sheet, $\alpha = 11.15^\circ$

Figure 6.09 - (Concluded)

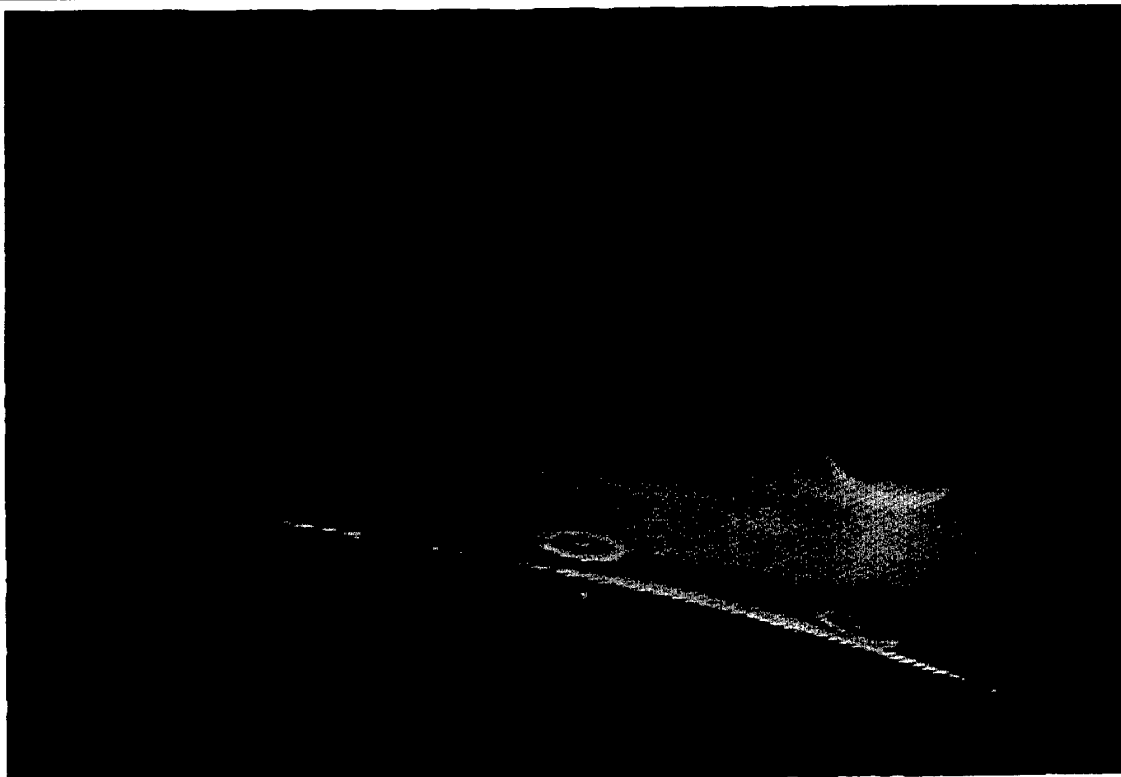


Sheet Position 1, Alpha = 11.75 deg



Sheet Position 3, Alpha = 11.74 deg

Figure 6.10 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 11.75$ deg

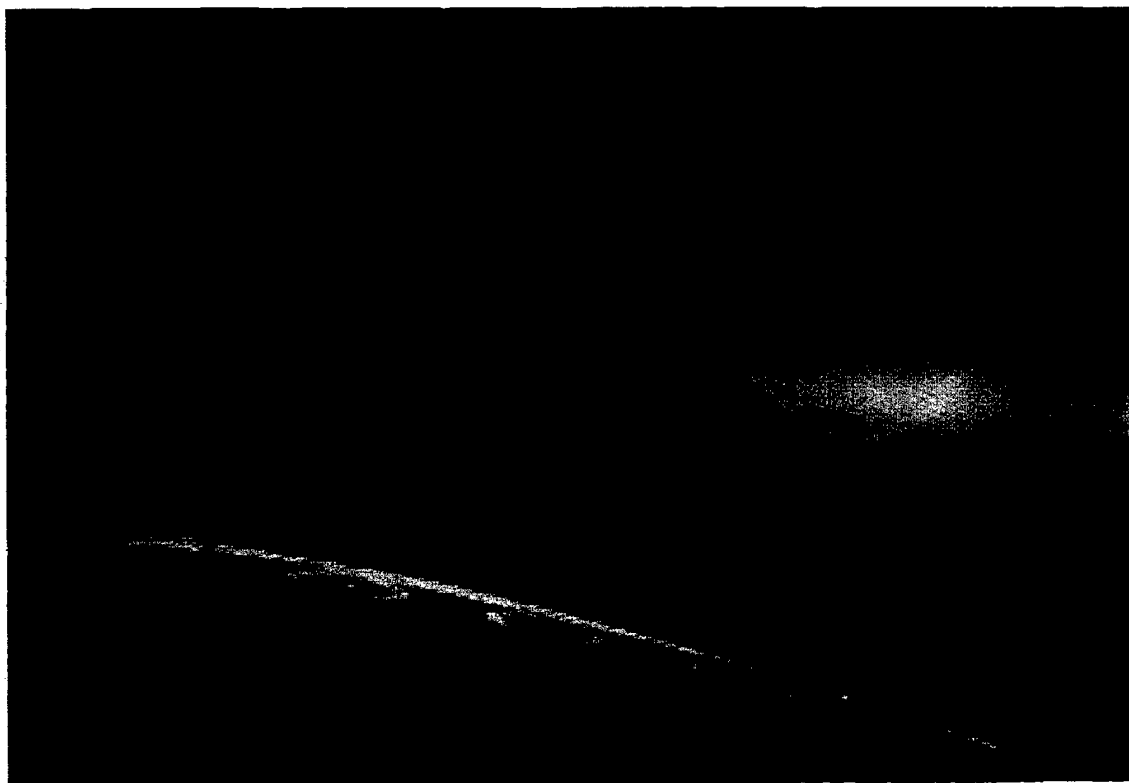


Sheet Position 14, $\alpha = 11.70^\circ$

NO DATA

Sweeping Sheet, $\alpha = 11.70^\circ$

Figure 6.10 - (Concluded)



Sheet Position 1, $\alpha = 12.64^\circ$



Sheet Position 3, $\alpha = 12.54^\circ$

Figure 6.11 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 12.59^\circ$

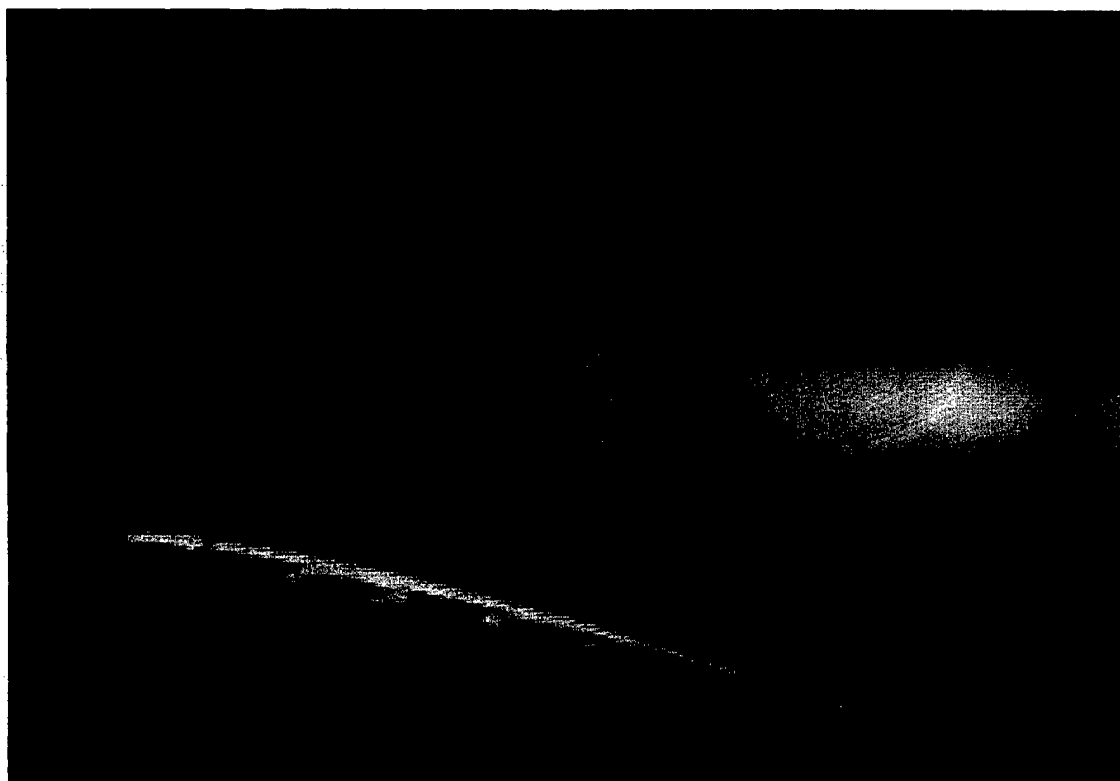


Sheet Position 14, $\alpha = 12.64$ deg

NO DATA

Sweeping Sheet, $\alpha = 12.64$ deg

Figure 6.11 - (Concluded)



Sheet Position 1, Alpha = 13.53 deg



Sheet Position 3, Alpha = 13.62 deg

Figure 6.12 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 13.58 deg

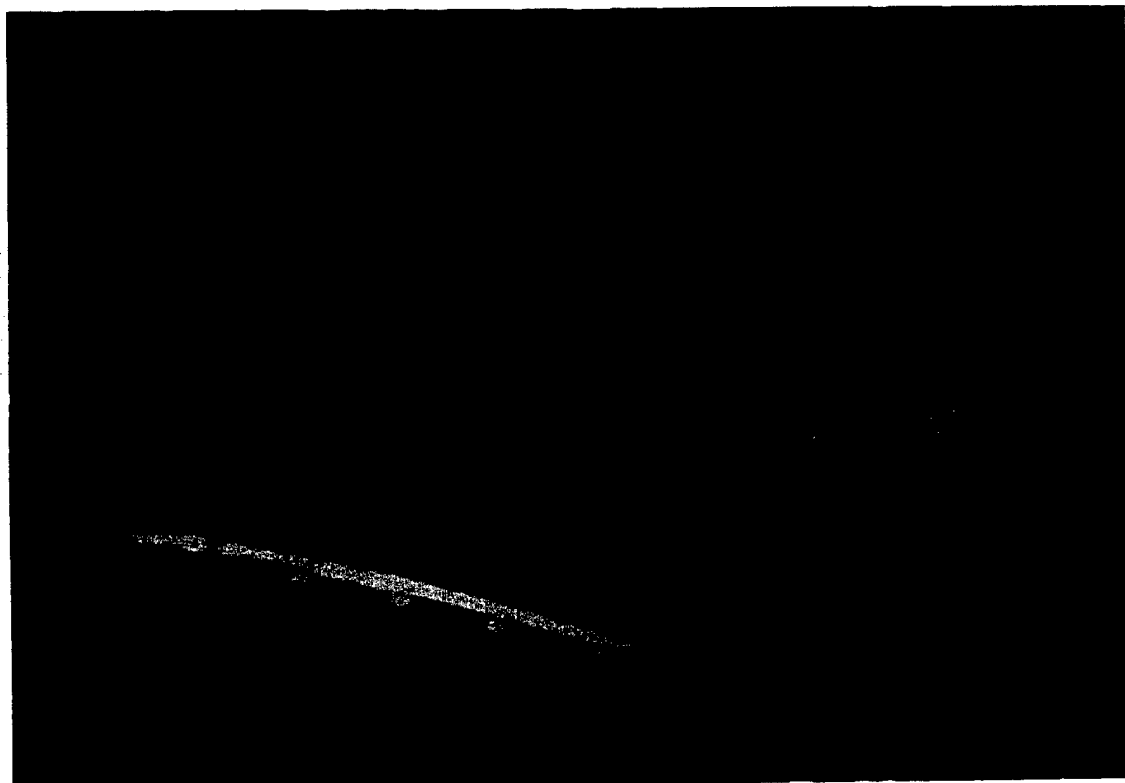


Sheet Position 14, $\alpha = 13.55^\circ$

NO DATA

Sweeping Sheet, $\alpha = 13.55^\circ$

Figure 6.12 - (Concluded)



Sheet Position 1, $\alpha = 14.64^\circ$



Sheet Position 3, $\alpha = 14.54^\circ$

Figure 6.13 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 14.59^\circ$



Sheet Position 14, $\alpha = 14.67^\circ$

NO DATA

Sweeping Sheet, $\alpha = 14.67^\circ$

Figure 6.13 - (Concluded)

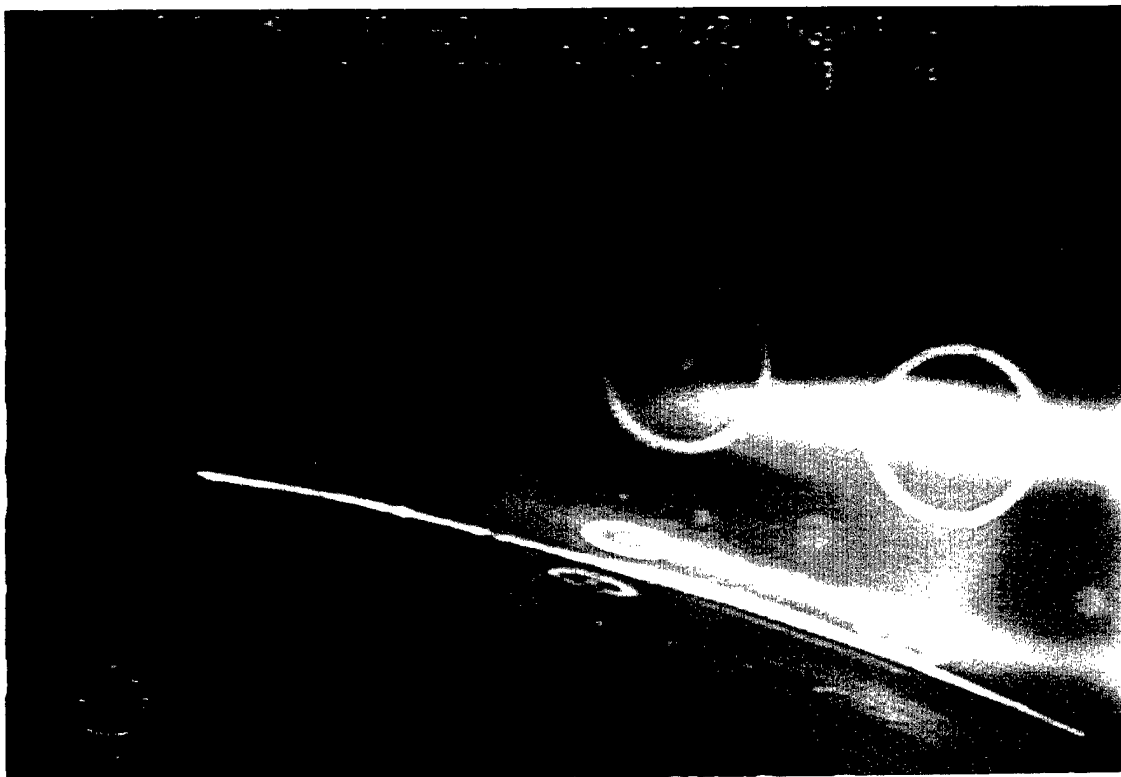


Sheet Position 1, Alpha = 15.53 deg



Sheet Position 3, Alpha = 15.66 deg

Figure 6.14 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 15.60 deg



Sheet Position 14, $\alpha = 15.59^\circ$

NO DATA

Sweeping Sheet, $\alpha = 15.59^\circ$

Figure 6.14 - (Concluded)

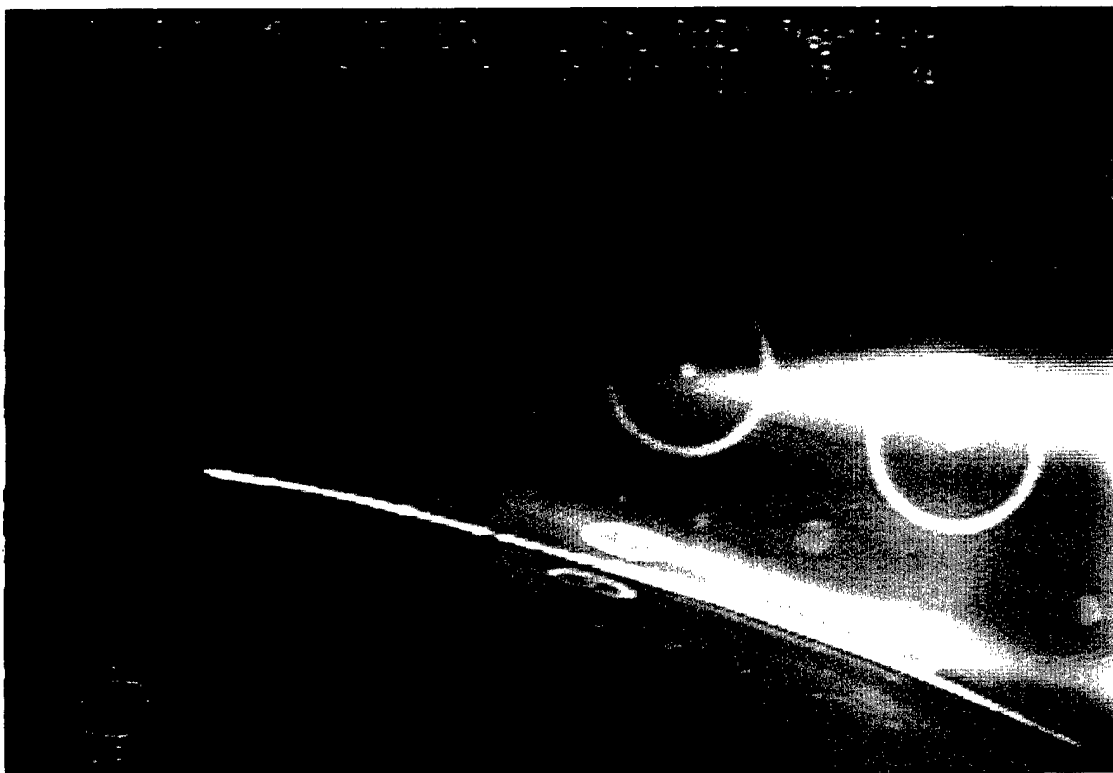


Sheet Position 1, Alpha = 16.62 deg



Sheet Position 3, Alpha = 16.41 deg

Figure 6.15 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 16.52 deg

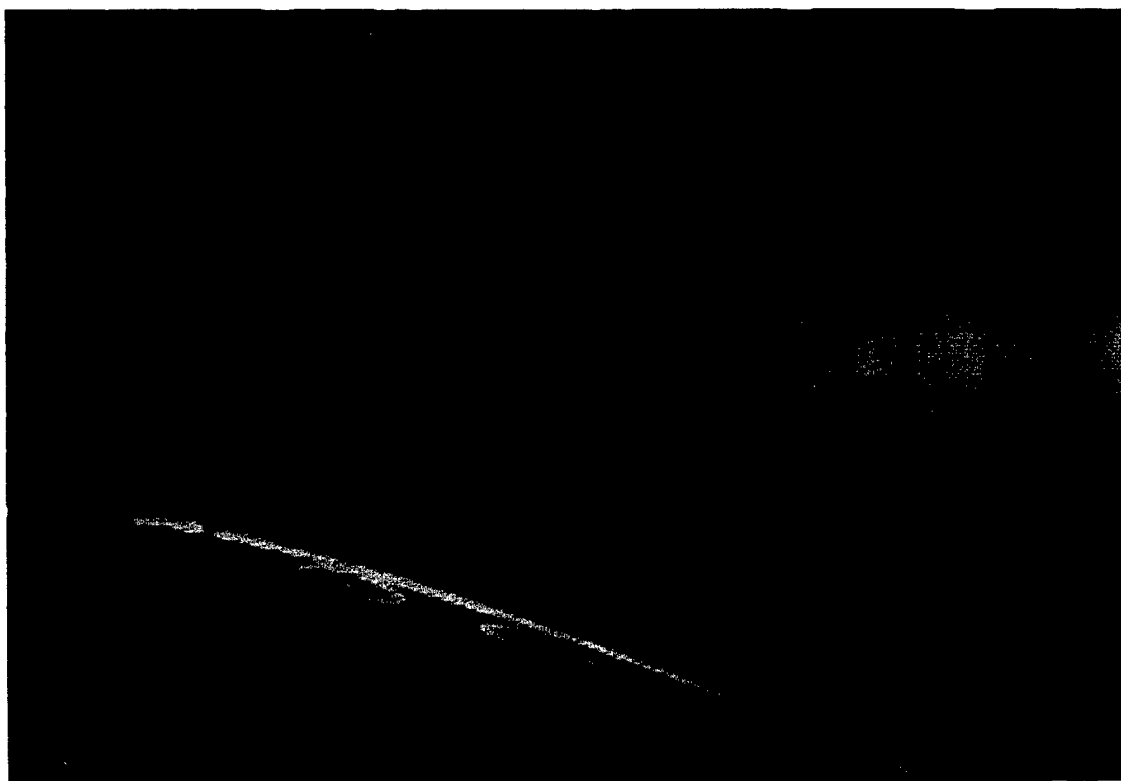


Sheet Position 14, $\alpha = 16.56$ deg

NO DATA

Sweeping Sheet, $\alpha = 16.56$ deg

Figure 6.15 - (Concluded)

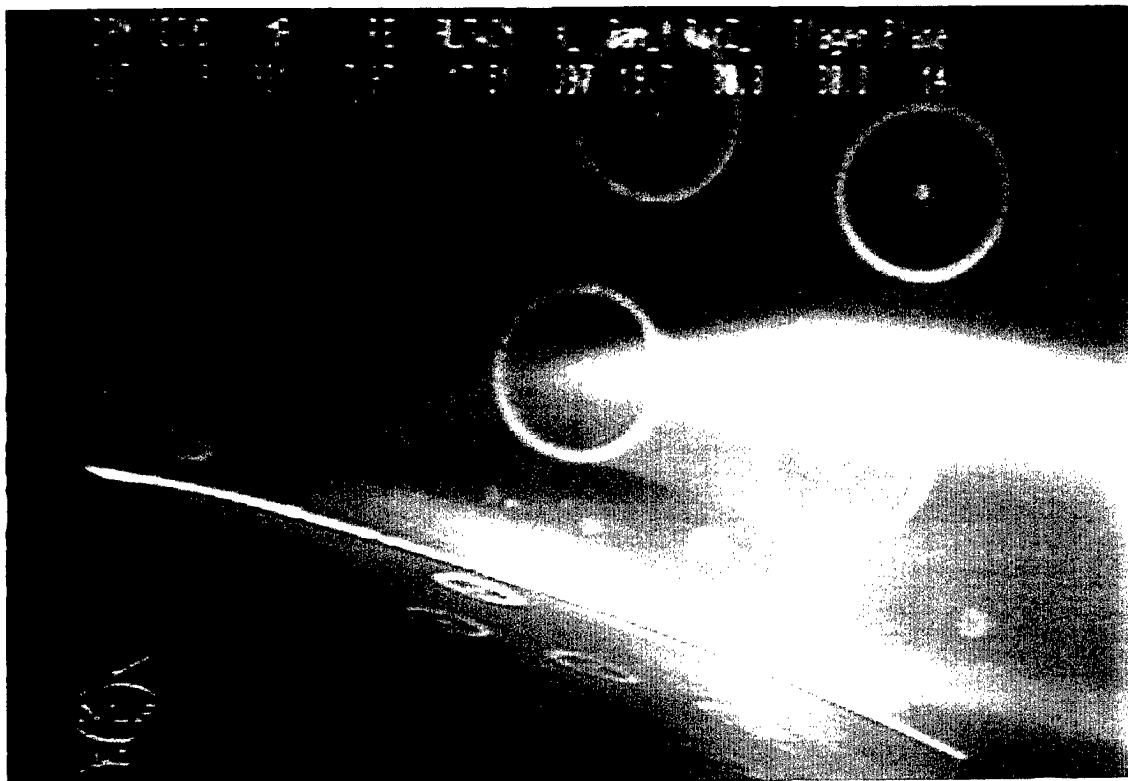


Sheet Position 1, Alpha = 17.54 deg

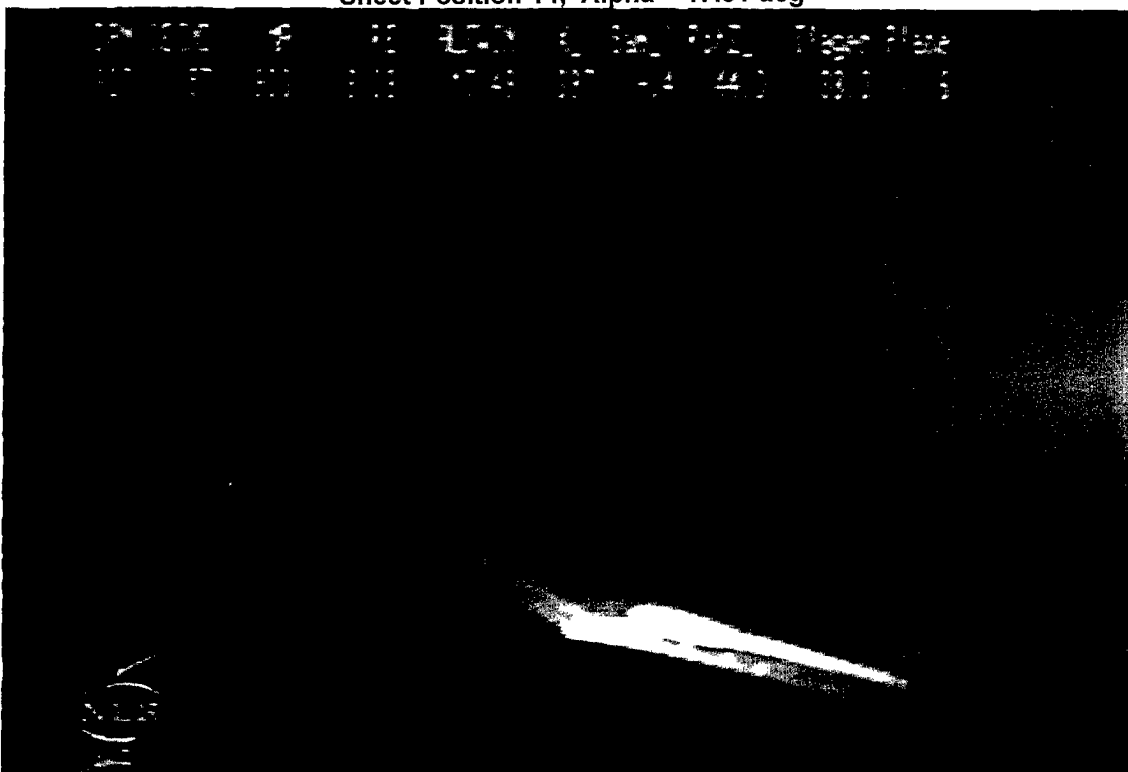


Sheet Position 3, Alpha = 17.53 deg

Figure 6.16 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 17.54$ deg



Sheet Position 14, Alpha = 17.51 deg



Sweeping Sheet, Alpha = 17.49 deg

Figure 6.16 - (Concluded)

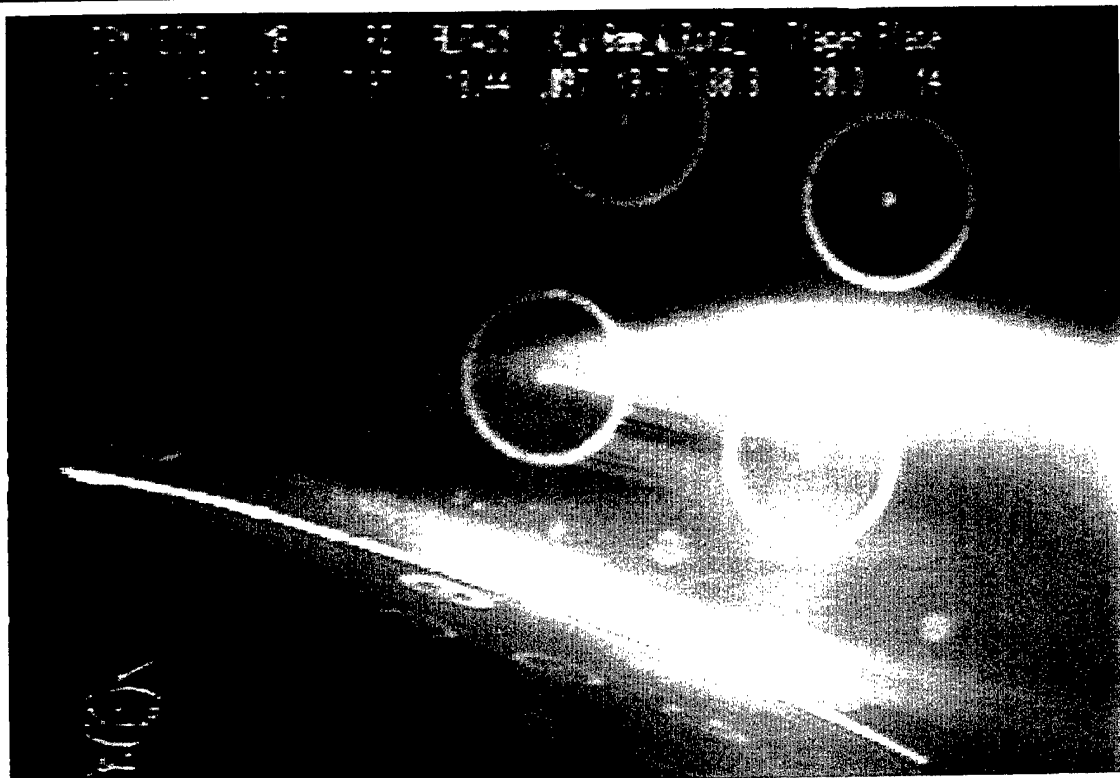


Sheet Position 1, Alpha = 18.50 deg



Sheet Position 3, Alpha = 18.46 deg

Figure 6.17 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 18.48 deg



Sheet Position 14, Alpha = 18.44 deg



Sweeping Sheet, Alpha = 18.36 deg

Figure 6.17 - (Concluded)

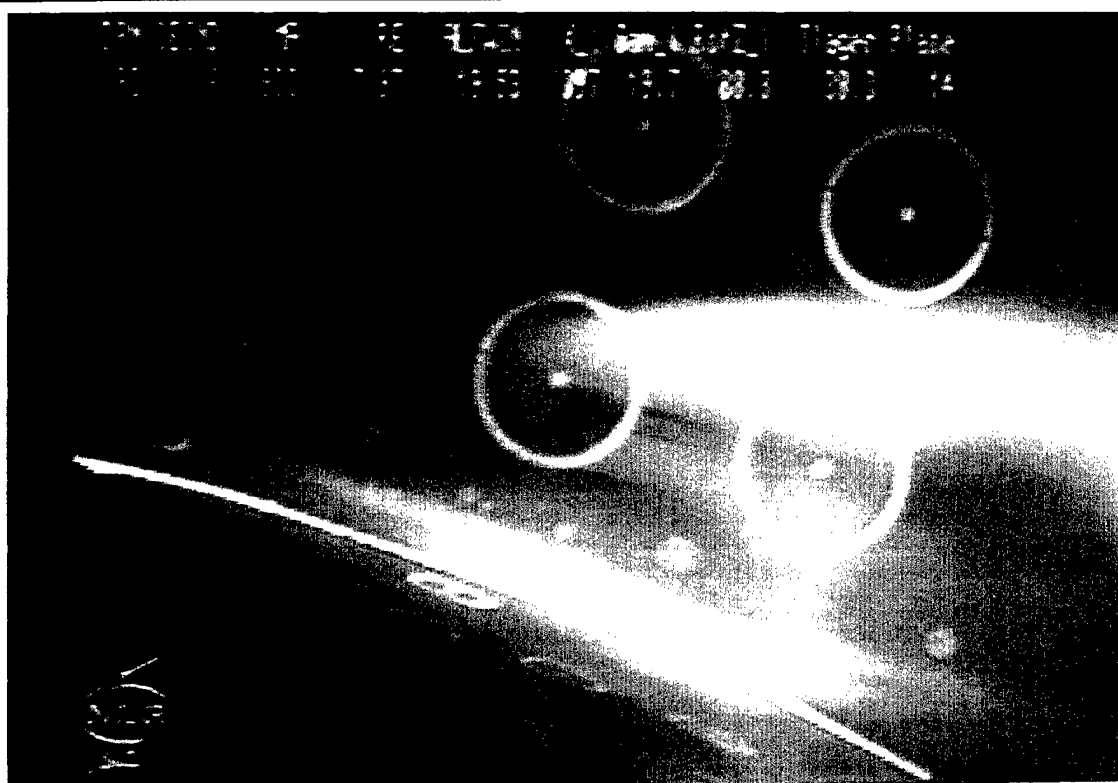


Sheet Position 1, Alpha = 19.40 deg



Sheet Position 3, Alpha = 19.53 deg

Figure 6.18 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 19.47^\circ$



Sheet Position 14, Alpha = 19.53 deg

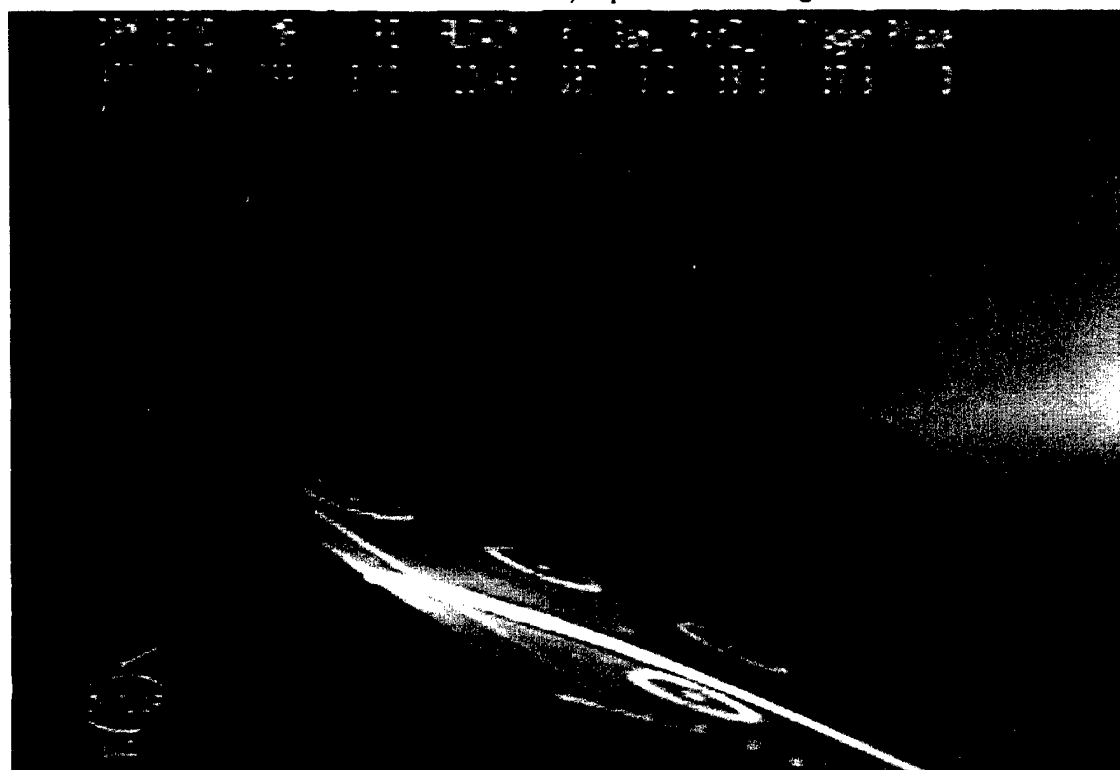


Sweeping Sheet, Alpha = 19.57 deg

Figure 6.18 - (Concluded)

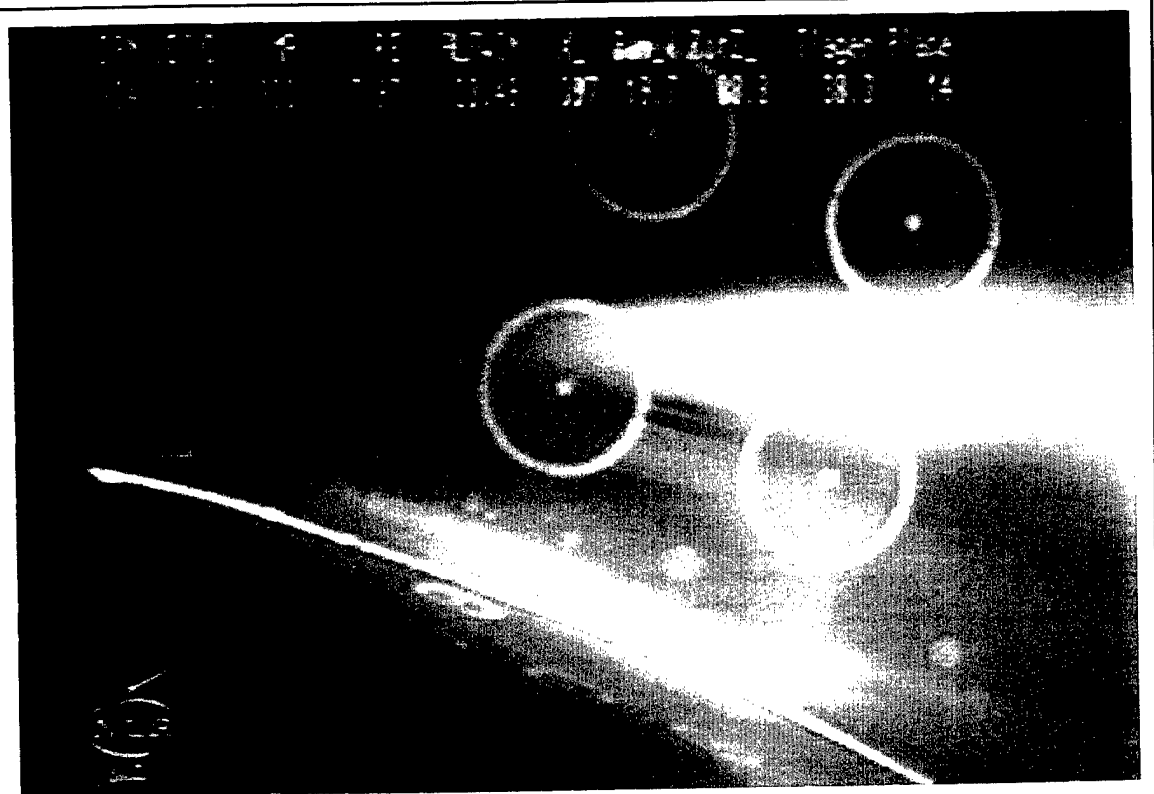


Sheet Position 1, Alpha = 20.55 deg

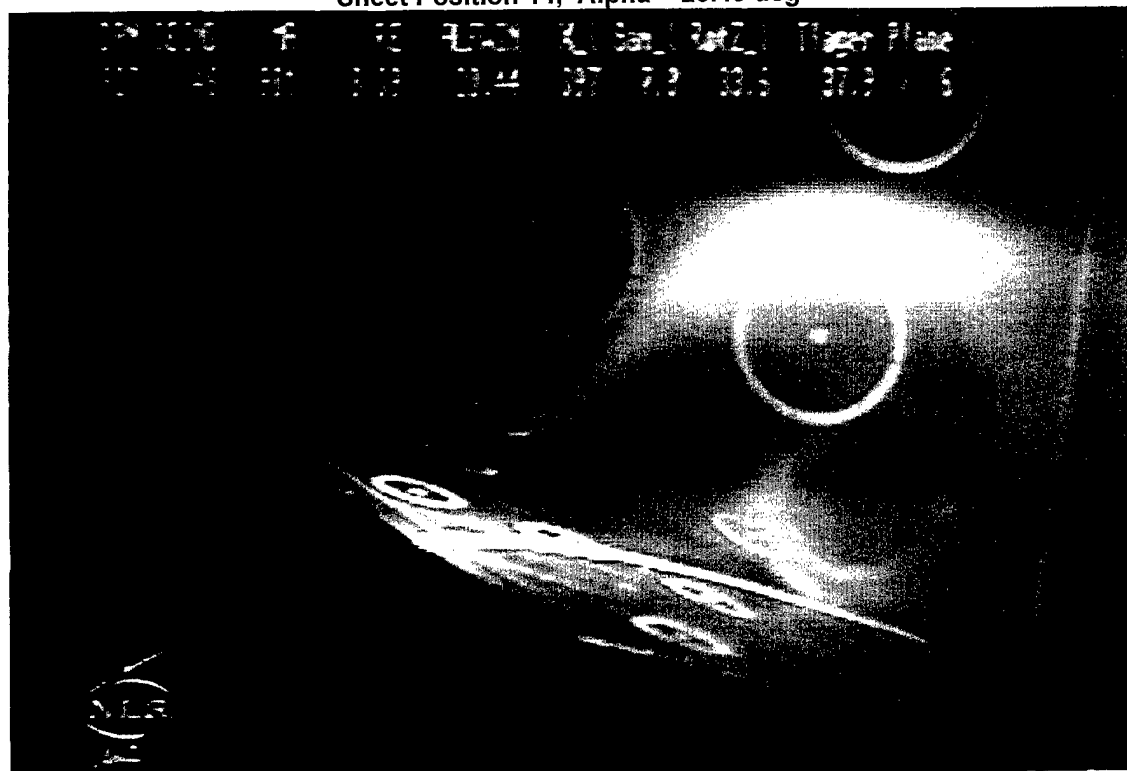


Sheet Position 3, Alpha = 20.49 deg

Figure 6.19 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 20.52 deg



Sheet Position 14, Alpha = 20.49 deg



Sweeping Sheet, Alpha = 20.44 deg

Figure 6.19 - (Concluded)

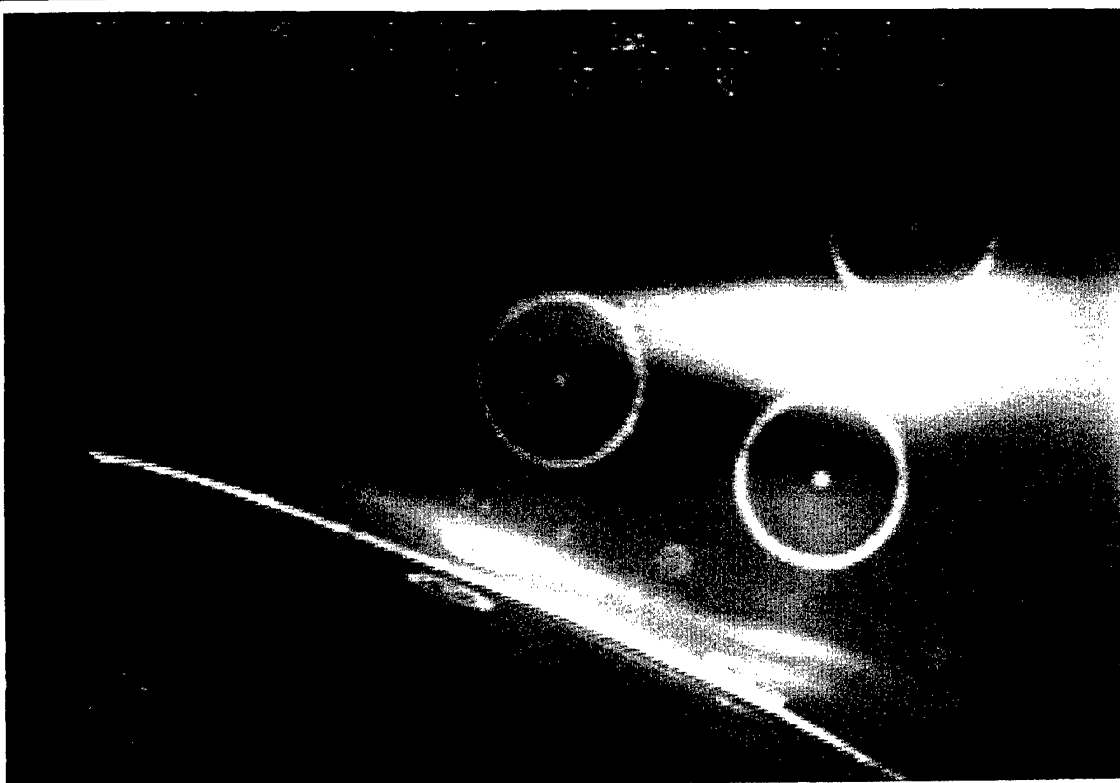


Sheet Position 1, Alpha = 21.67 deg

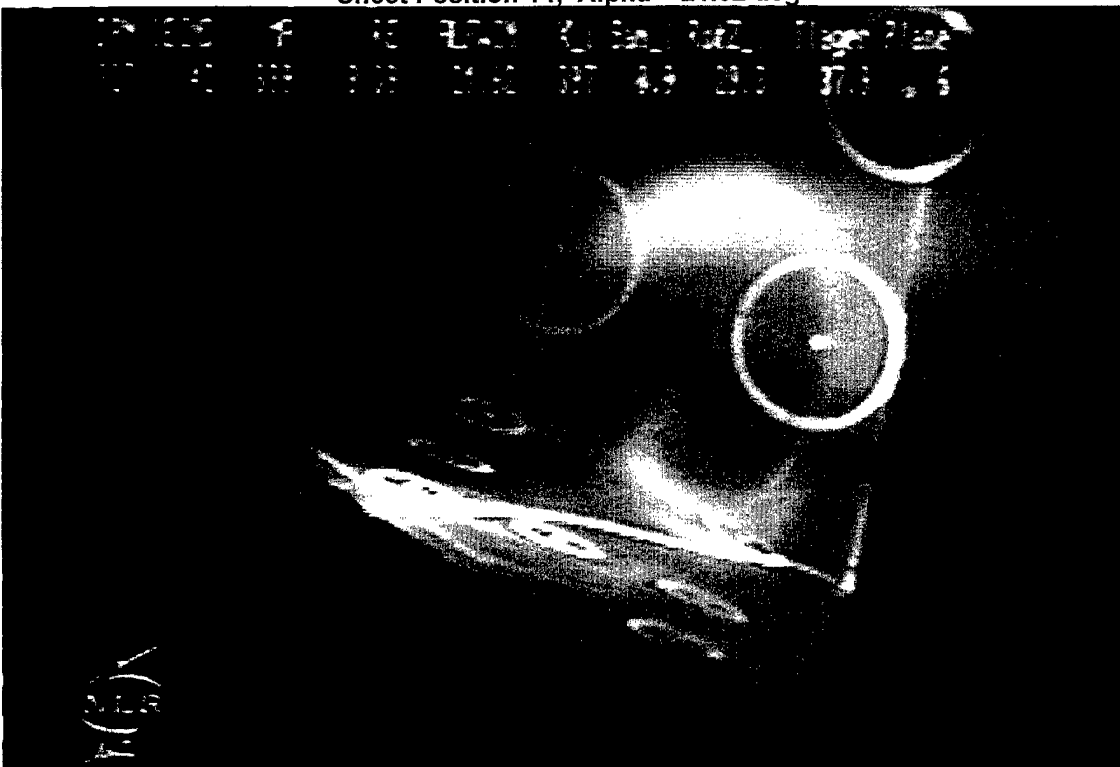


Sheet Position 3, Alpha = 21.58 deg

Figure 6.20 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 21.63 deg



Sheet Position 14, Alpha = 21.62 deg

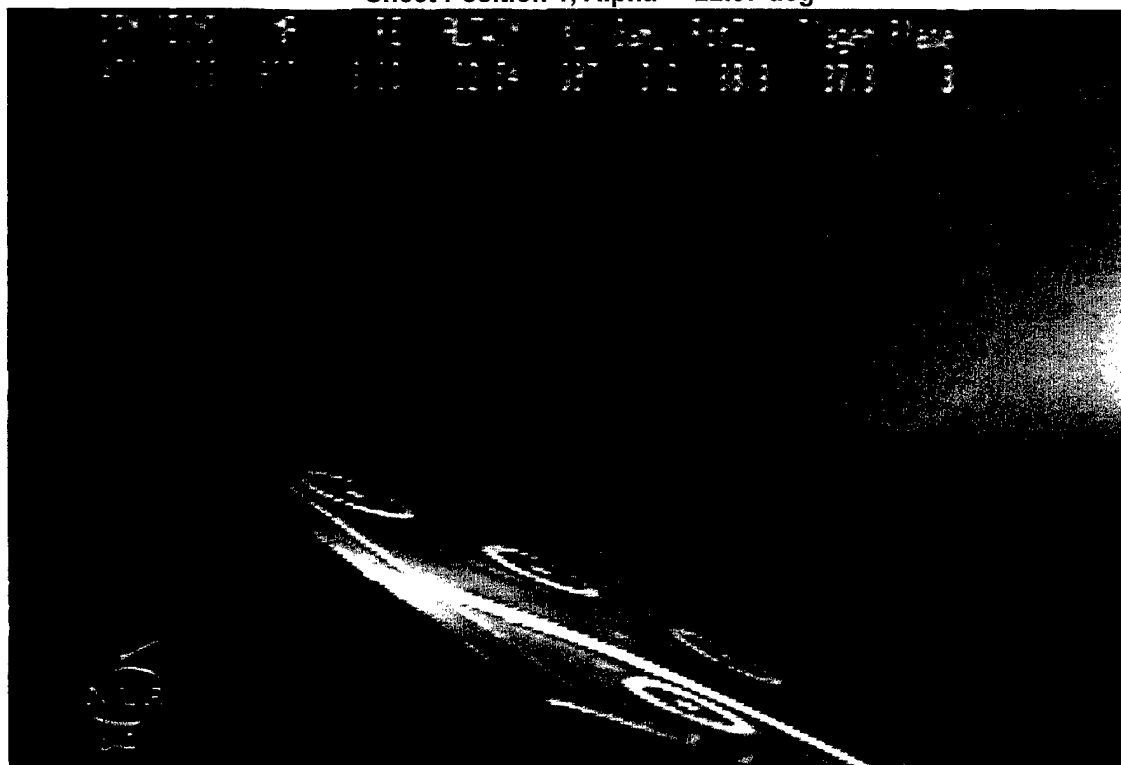


Sweeping Sheet, Alpha = 21.62 deg

Figure 6.20 - (Concluded)

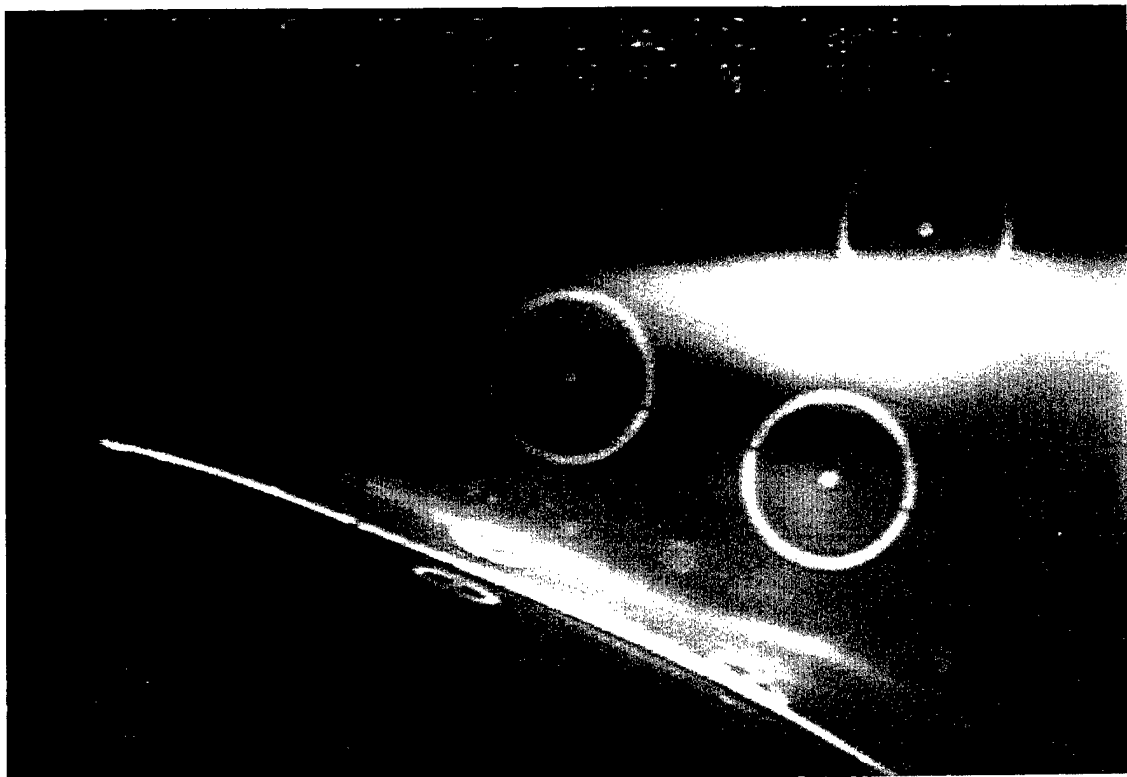


Sheet Position 1, Alpha = 22.57 deg

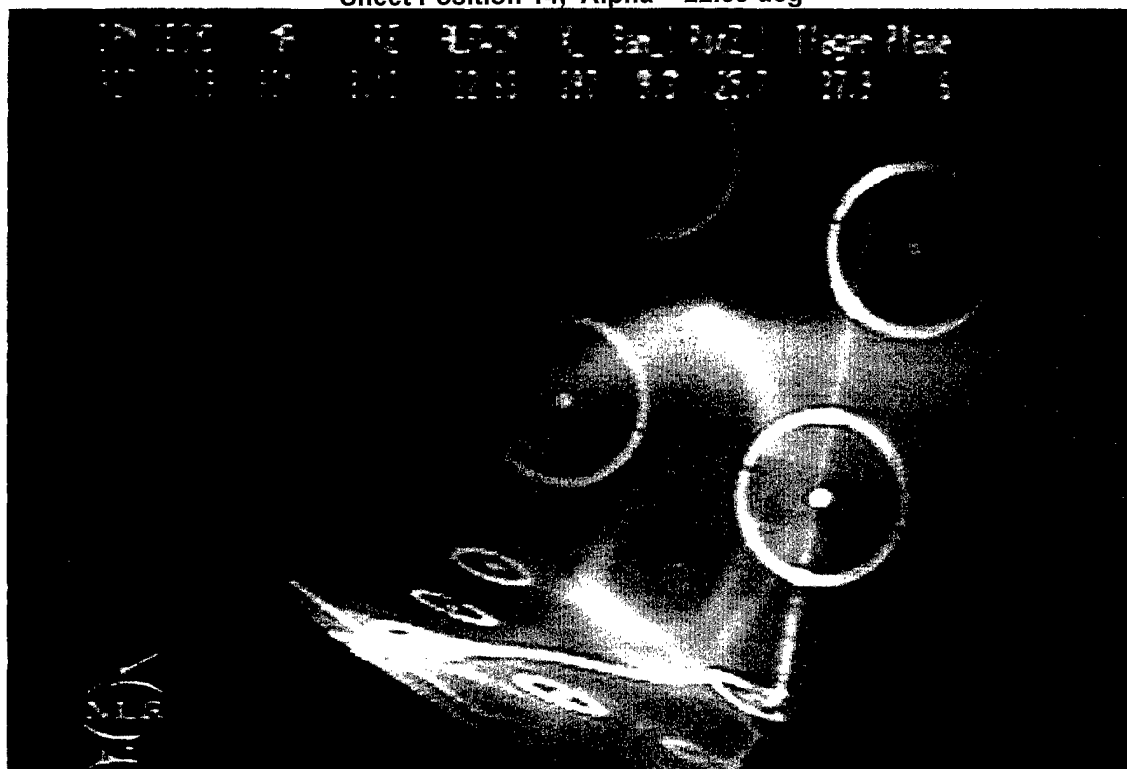


Sheet Position 3, Alpha = 22.54 deg

Figure 6.21 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 22.56^\circ$

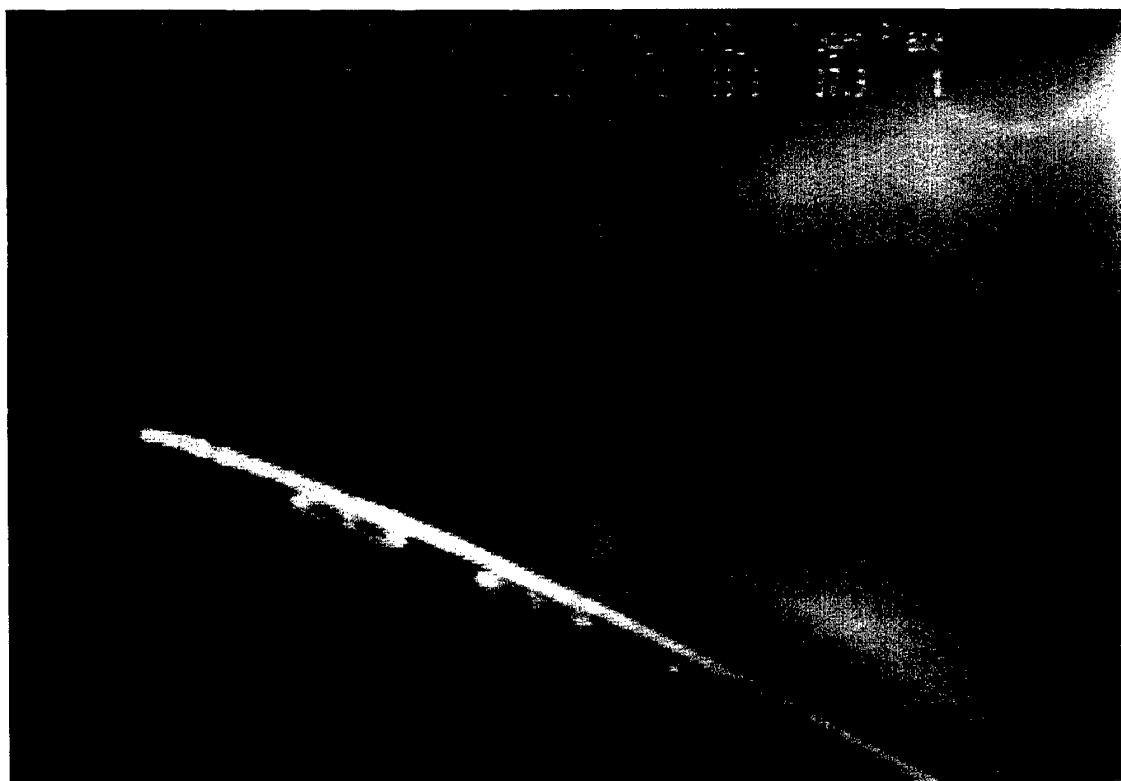


Sheet Position 14, Alpha = 22.65 deg

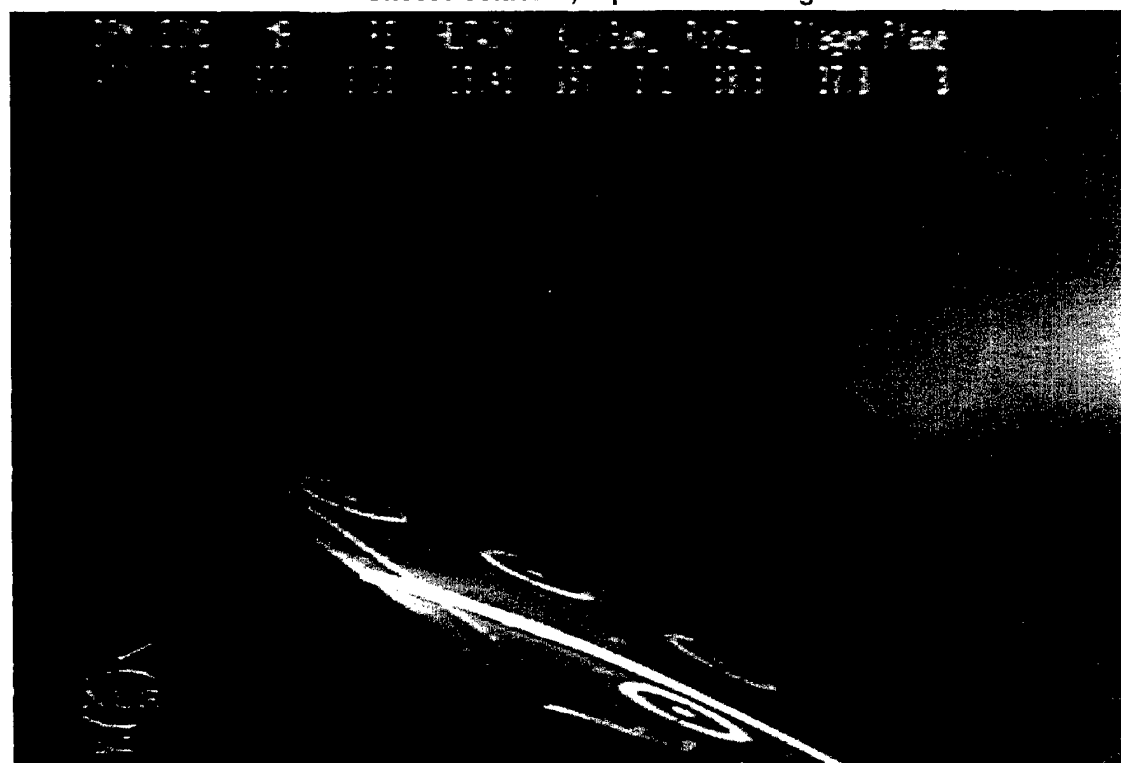


Sweeping Sheet, Alpha = 22.63 deg

Figure 6.21 - (Concluded)

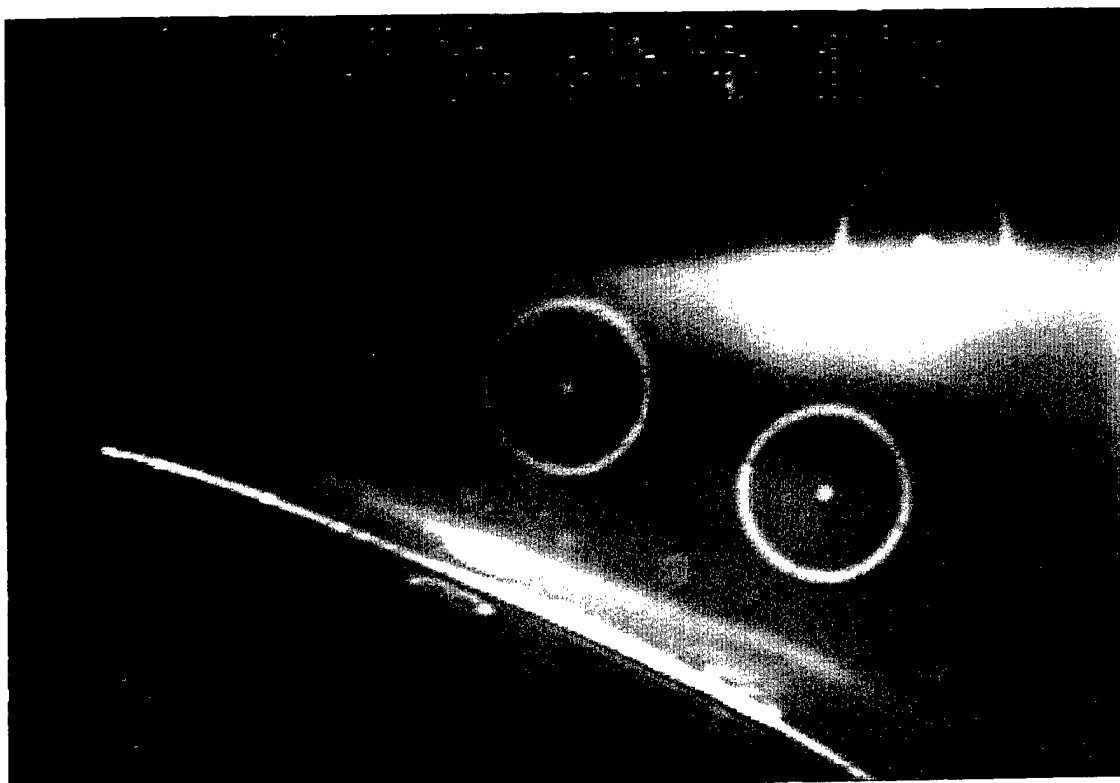


Sheet Position 1, Alpha = 23.50 deg

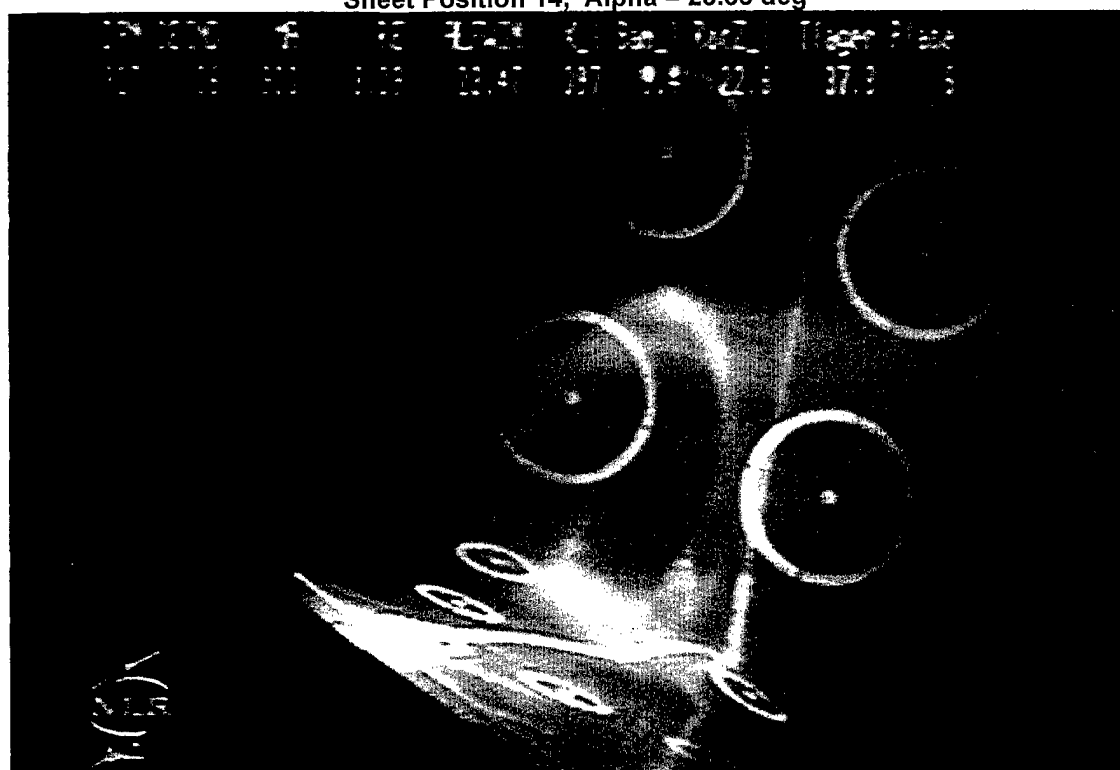


Sheet Position 3, Alpha = 23.43 deg

Figure 6.22 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 23.47^\circ$



Sheet Position 14, Alpha = 23.55 deg

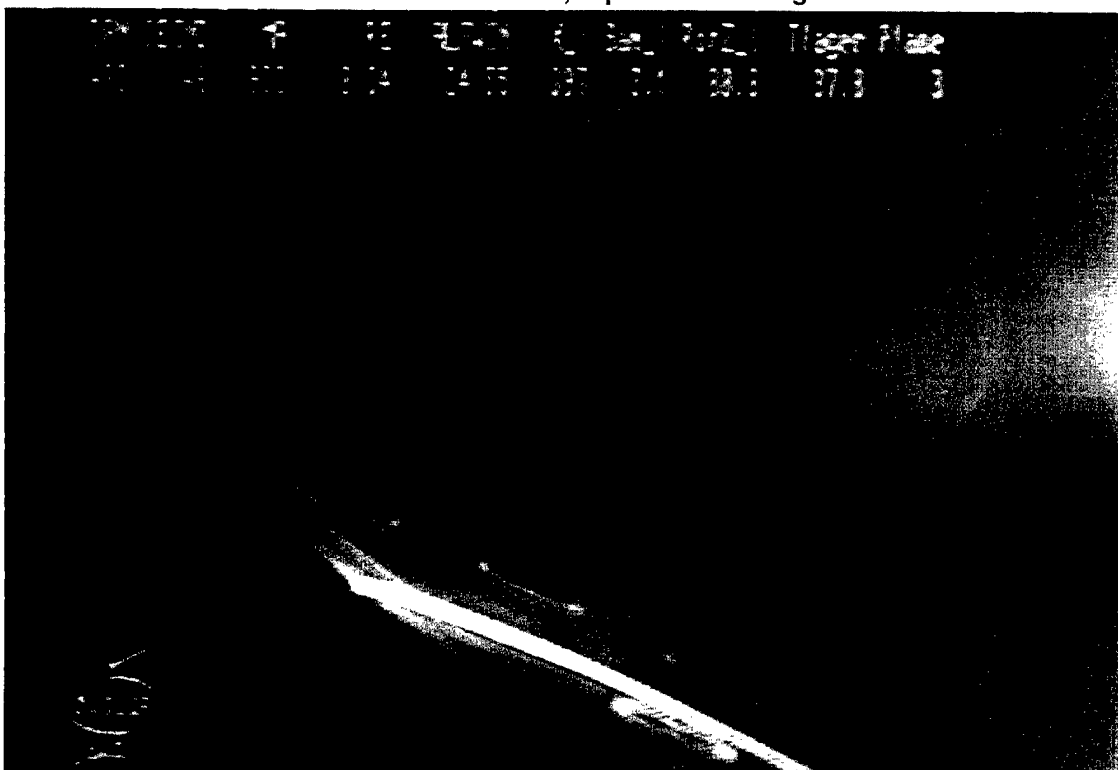


Sweeping Sheet, Alpha = 23.47 deg

Figure 6.22 - (Concluded)



Sheet Position 1, Alpha = 24.48 deg



Sheet Position 3, Alpha = 24.55 deg

Figure 6.23 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 24.52^\circ$

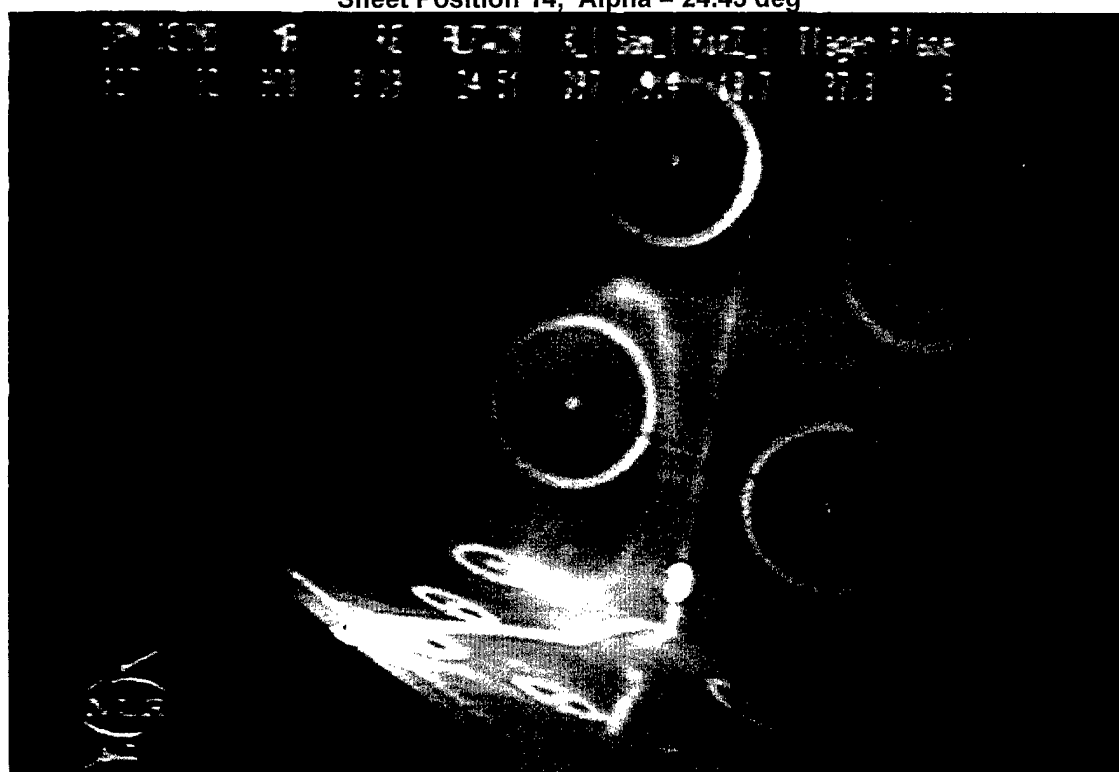
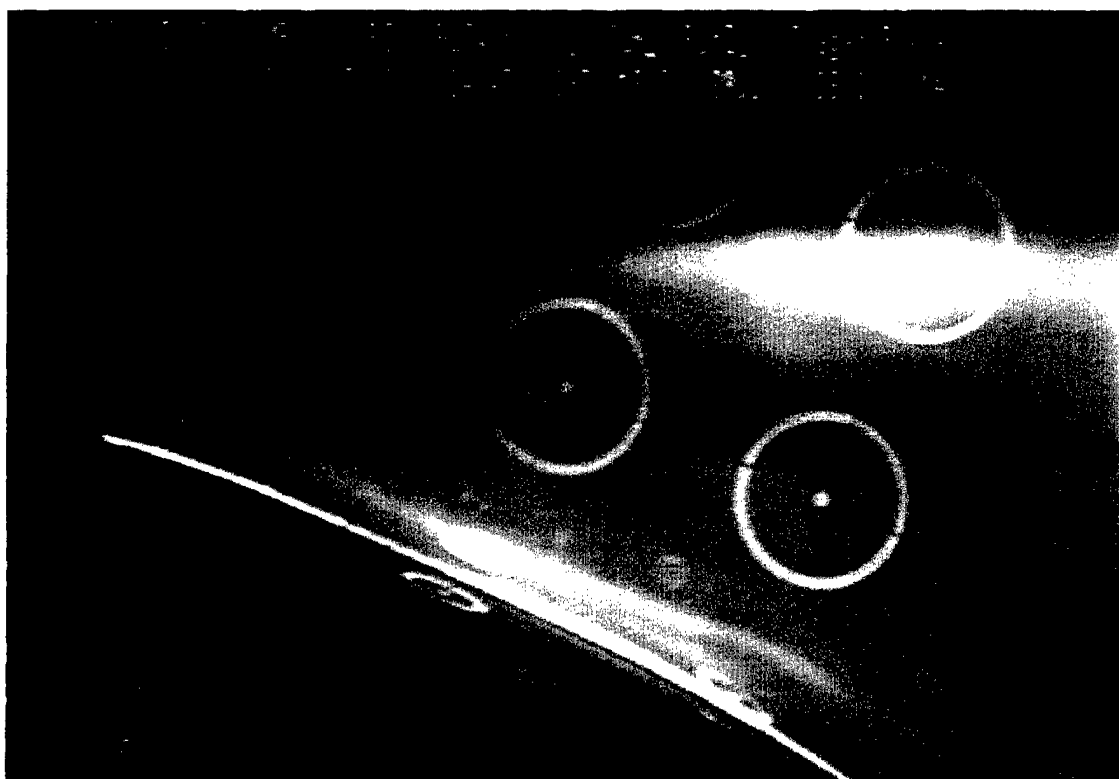
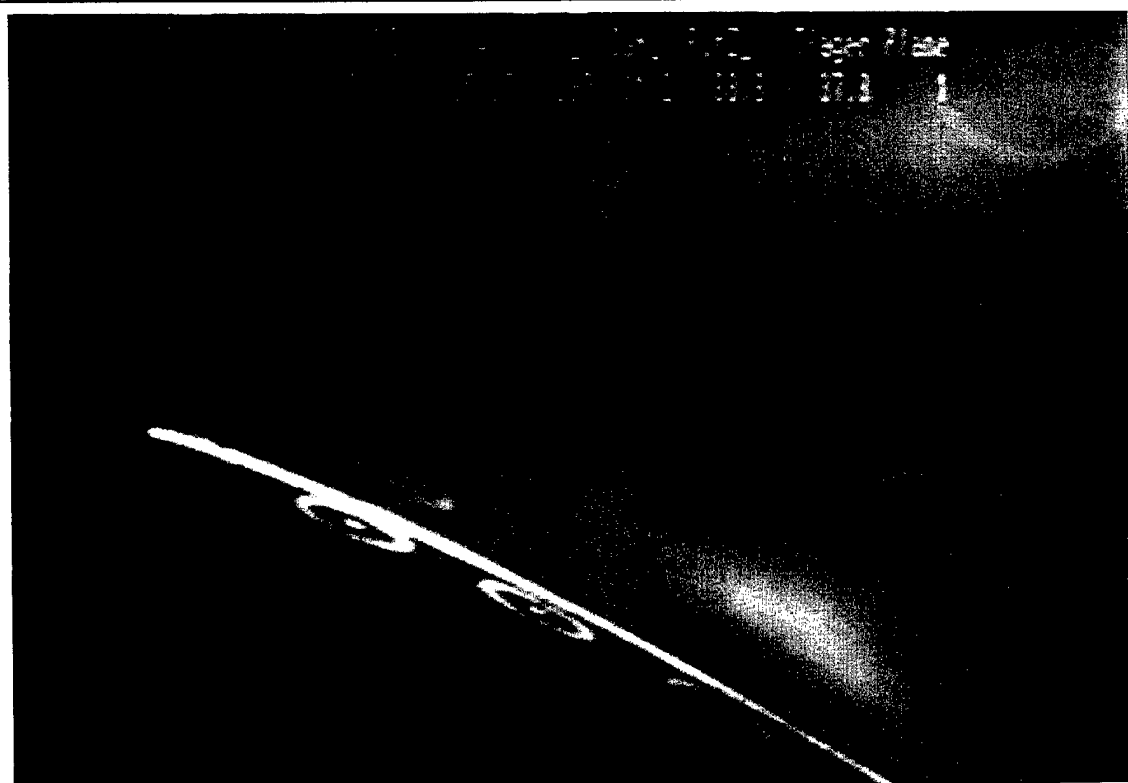


Figure 6.23 - (Concluded)

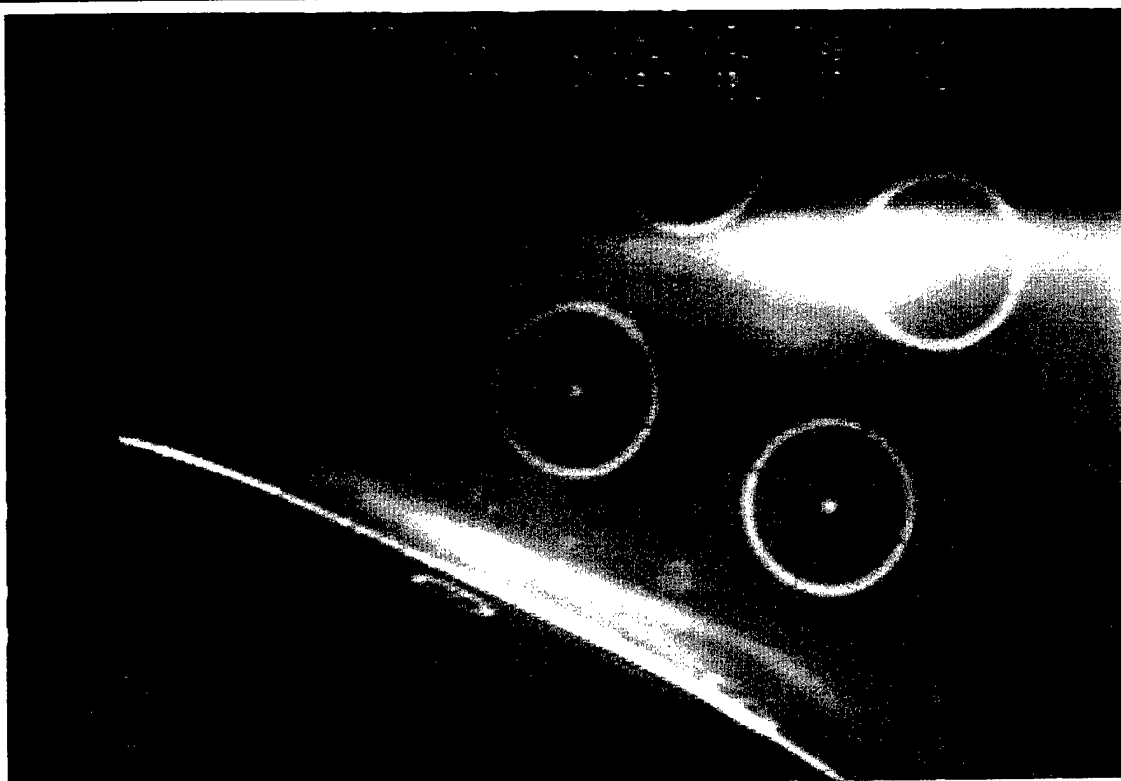


Sheet Position 1, Alpha = 25.57 deg

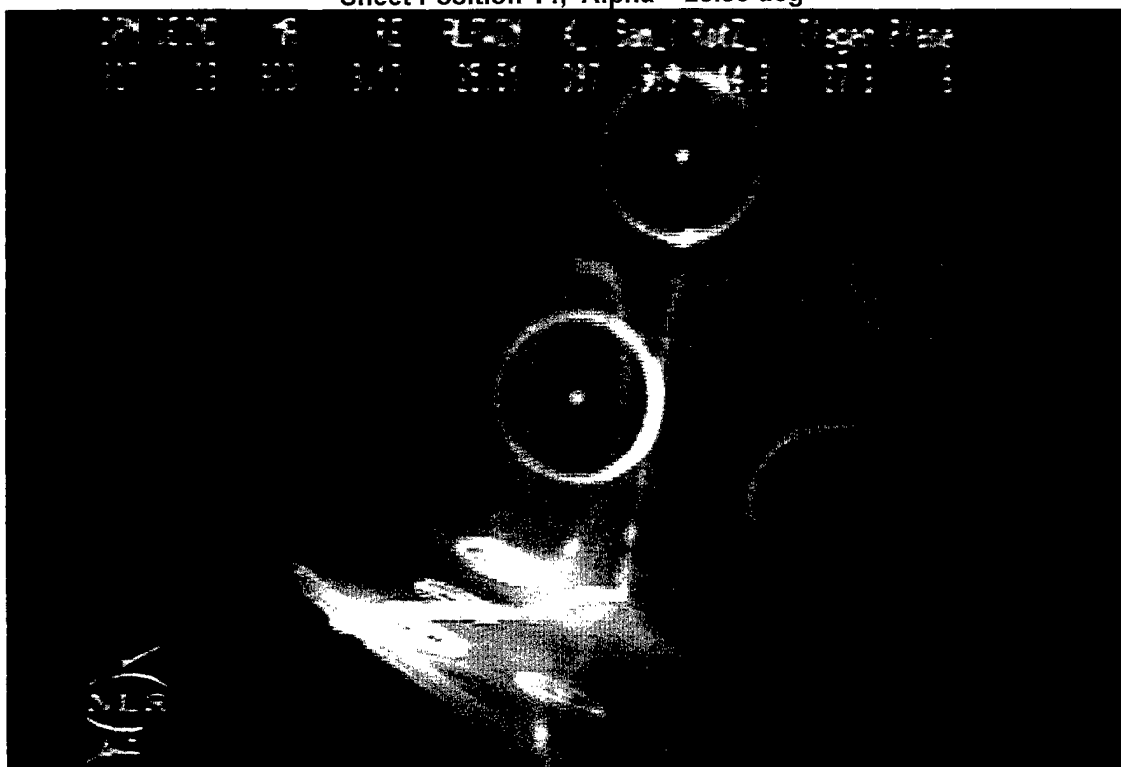


Sheet Position 3, Alpha = 25.67deg

Figure 6.24 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 25.62 deg



Sheet Position 14, Alpha = 25.56 deg



Sweeping Sheet, Alpha = 25.51 deg

Figure 6.24 - (Concluded)

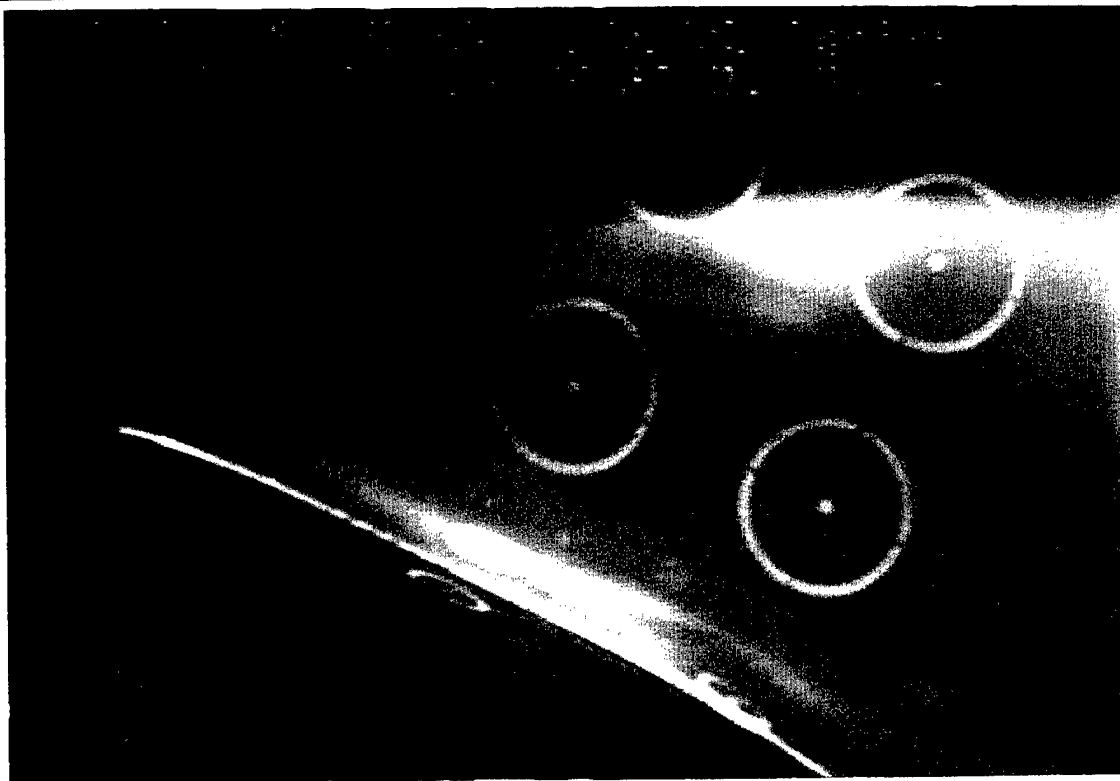


Sheet Position 1, Alpha = 26.46 deg



Sheet Position 3, Alpha = 26.56 deg

Figure 6.25 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 26.51^\circ$

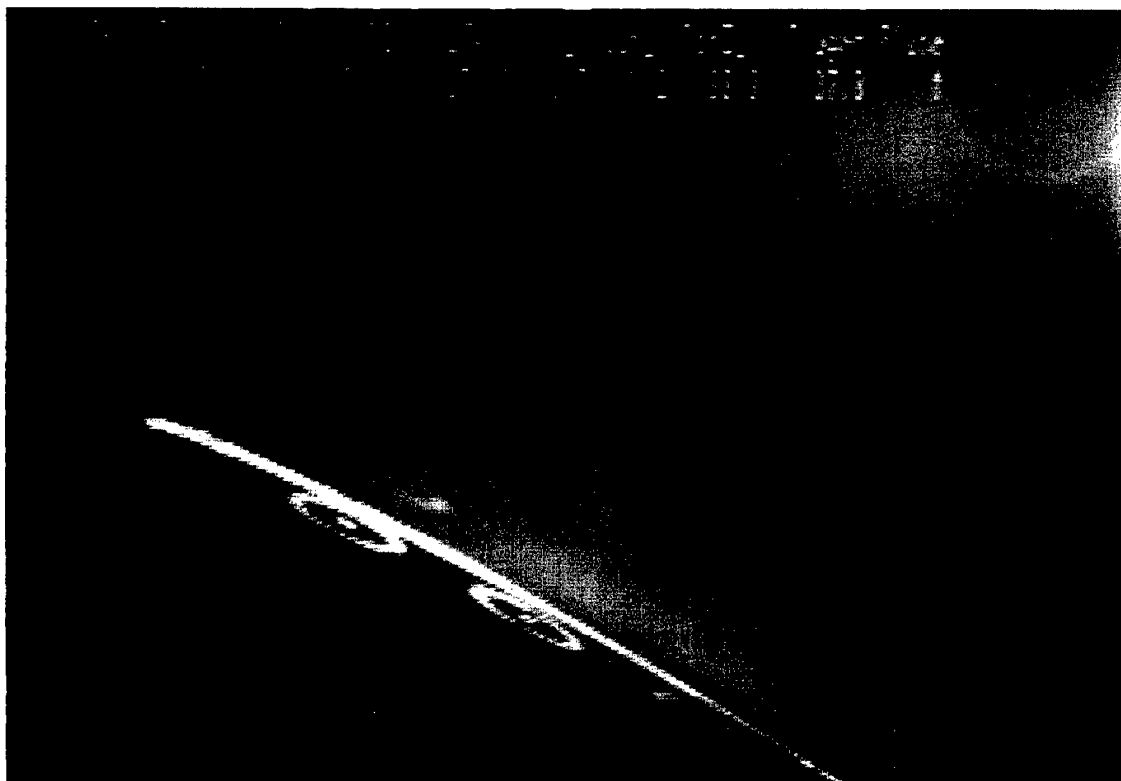


Sheet Position 14, $\alpha = 26.48^\circ$



Sweeping Sheet, $\alpha = 26.51^\circ$

Figure 6.25 - (Concluded)

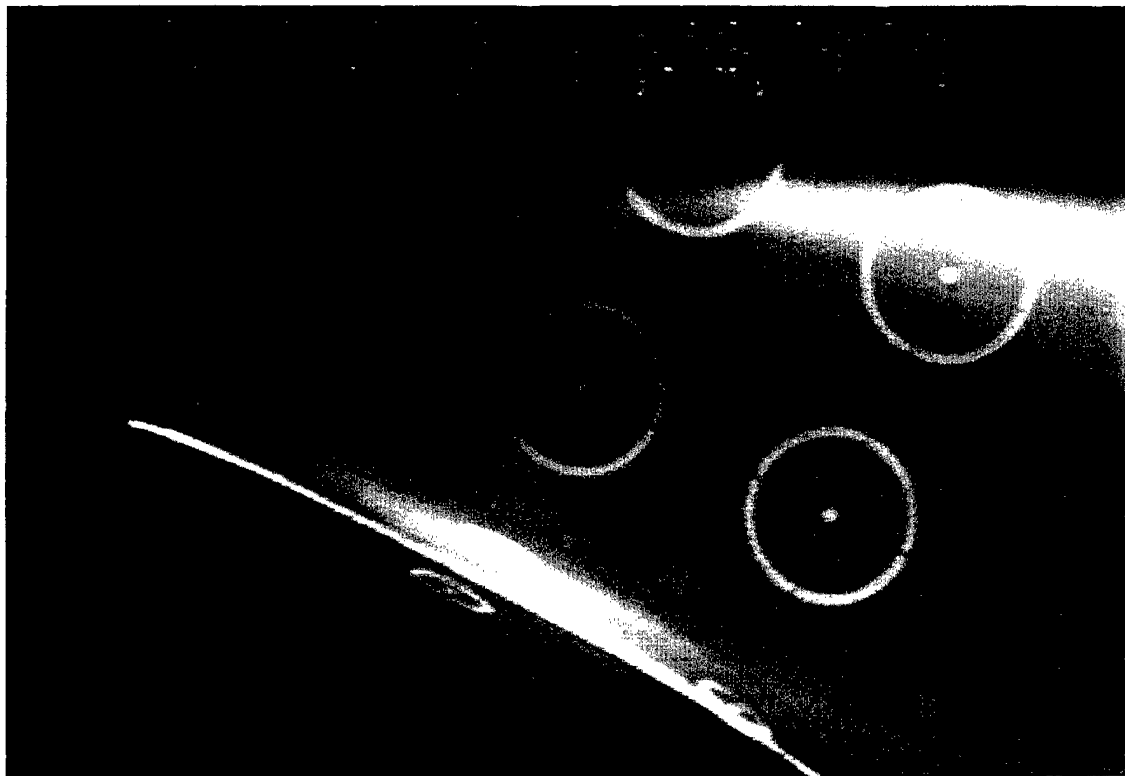


Sheet Position 1, Alpha = 27.48 deg

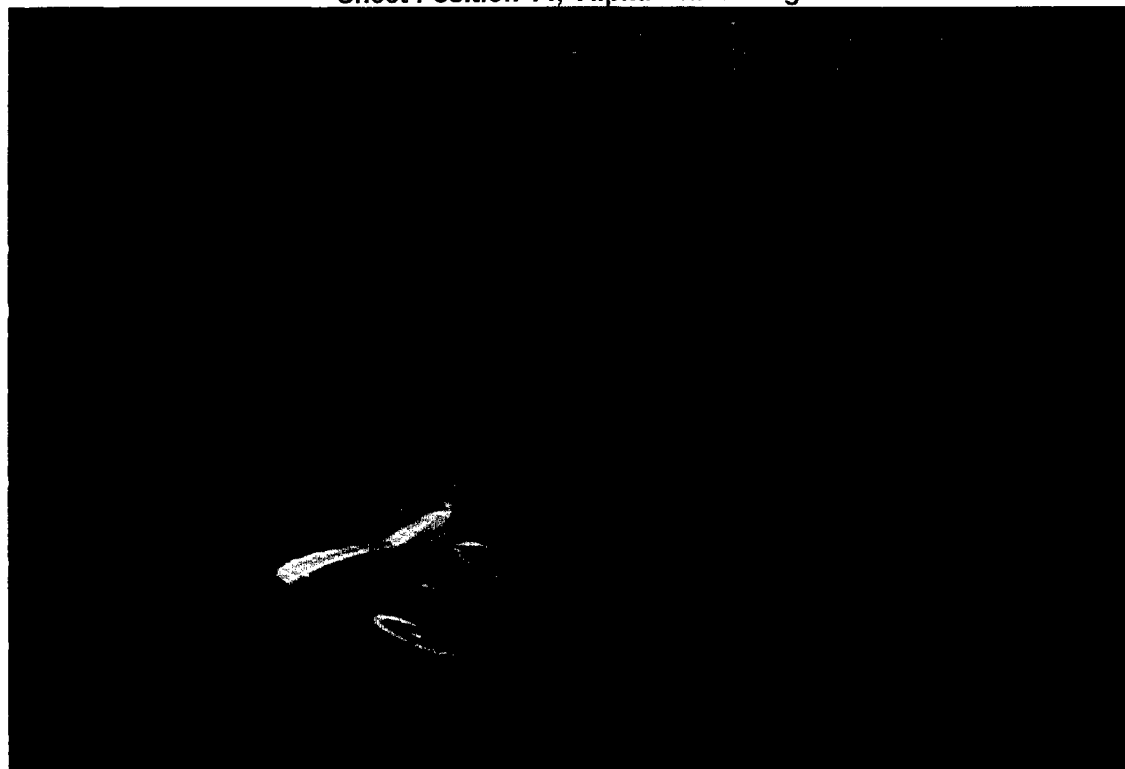


Sheet Position 3, Alpha = 27.61 deg

Figure 6.26 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 27.55 deg



Sheet Position 14, $\alpha = 27.61^\circ$

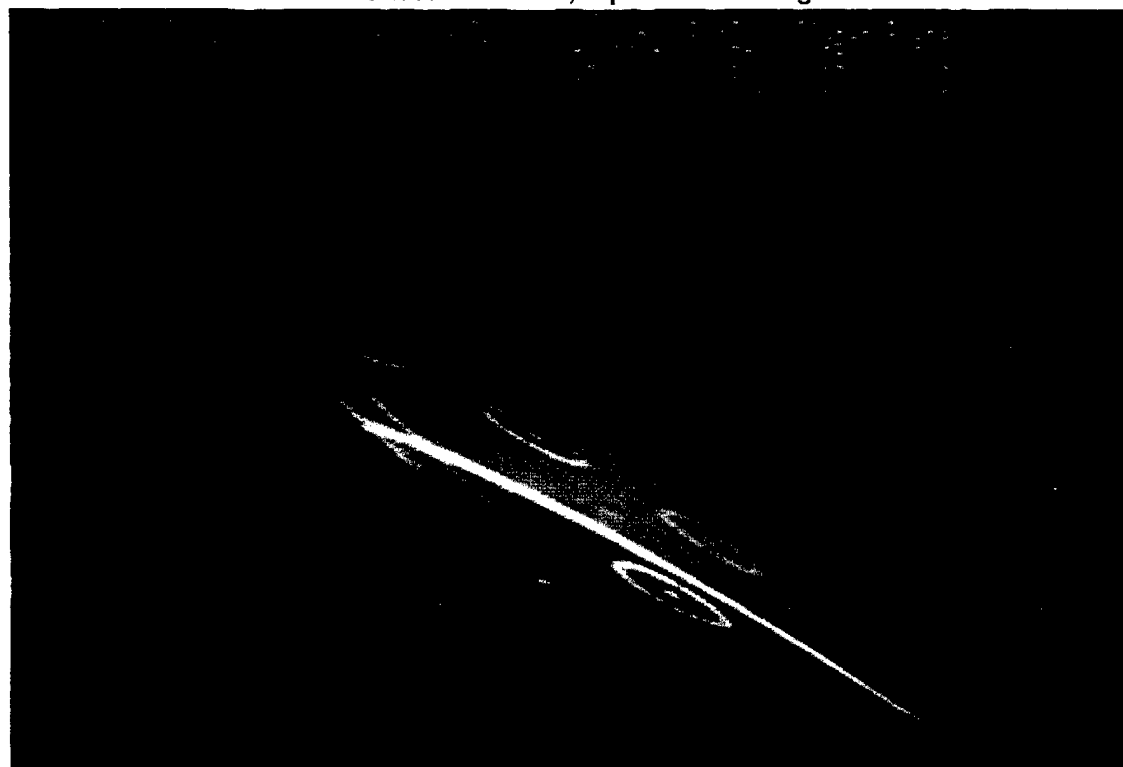


Sweeping Sheet, $\alpha = 27.67^\circ$

Figure 6.26 - (Concluded)



Sheet Position 1, Alpha = 28.56 deg



Sheet Position 3, Alpha = 28.52 deg

Figure 6.27 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 28.54$ deg

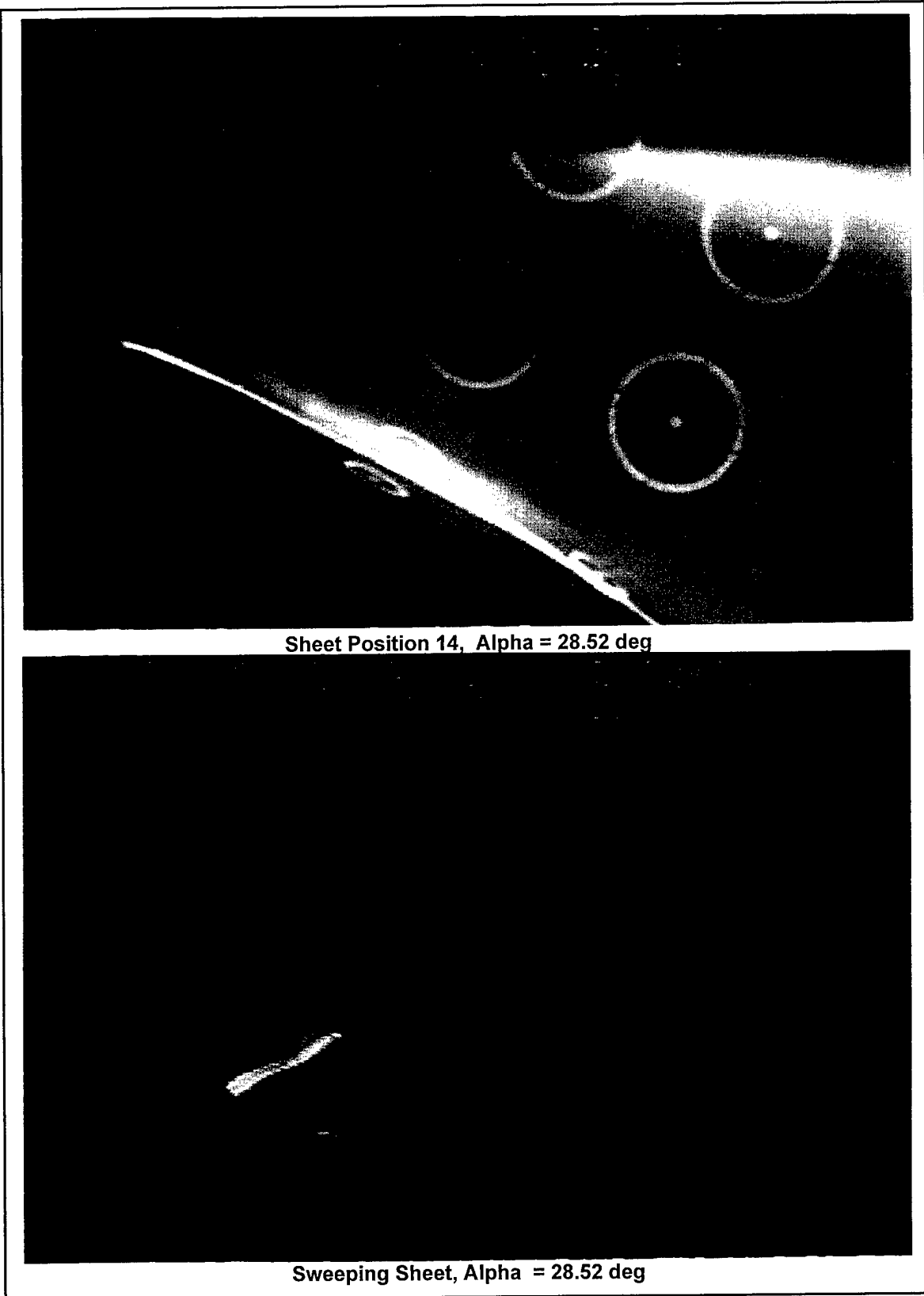
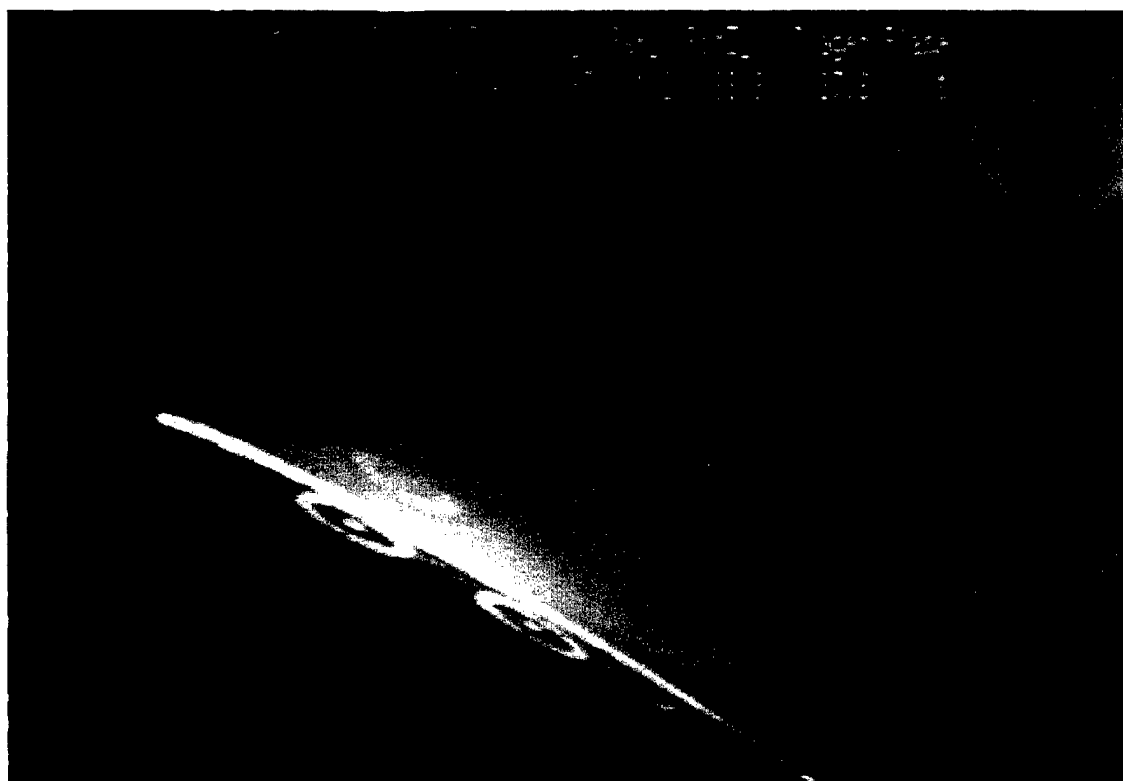


Figure 6.27 - (Concluded)

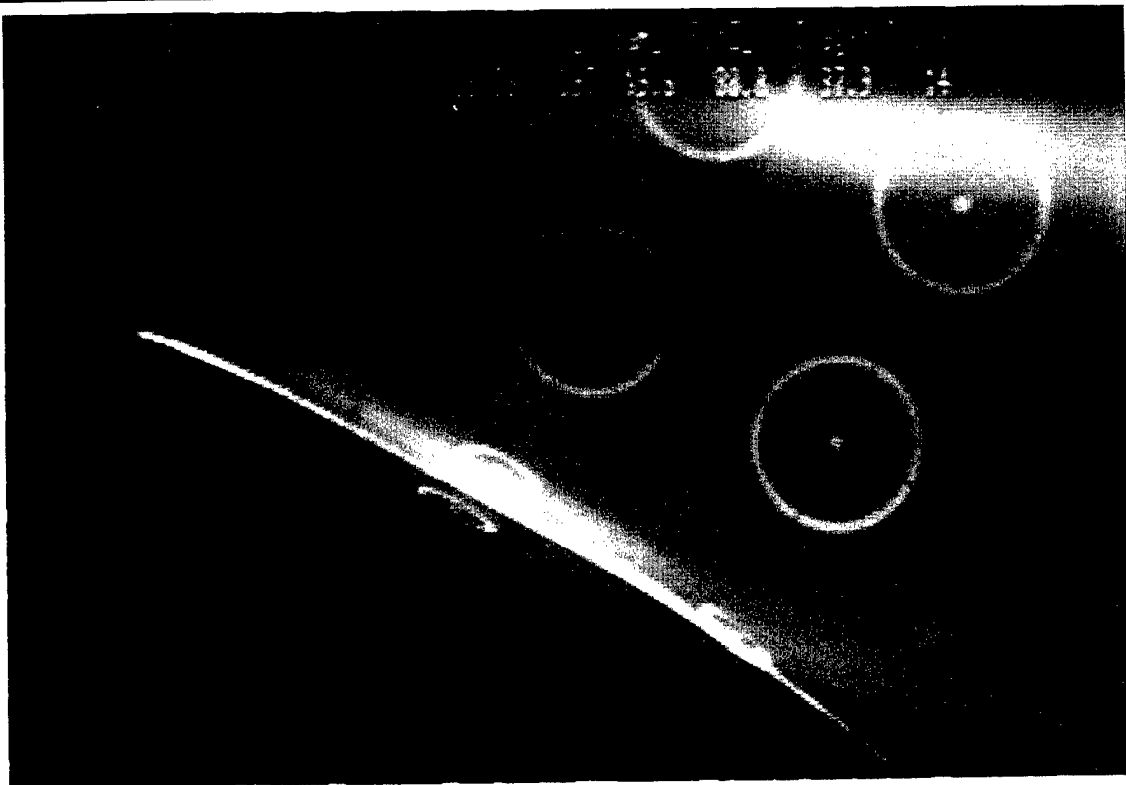


Sheet Position 1, Alpha = 29.49 deg

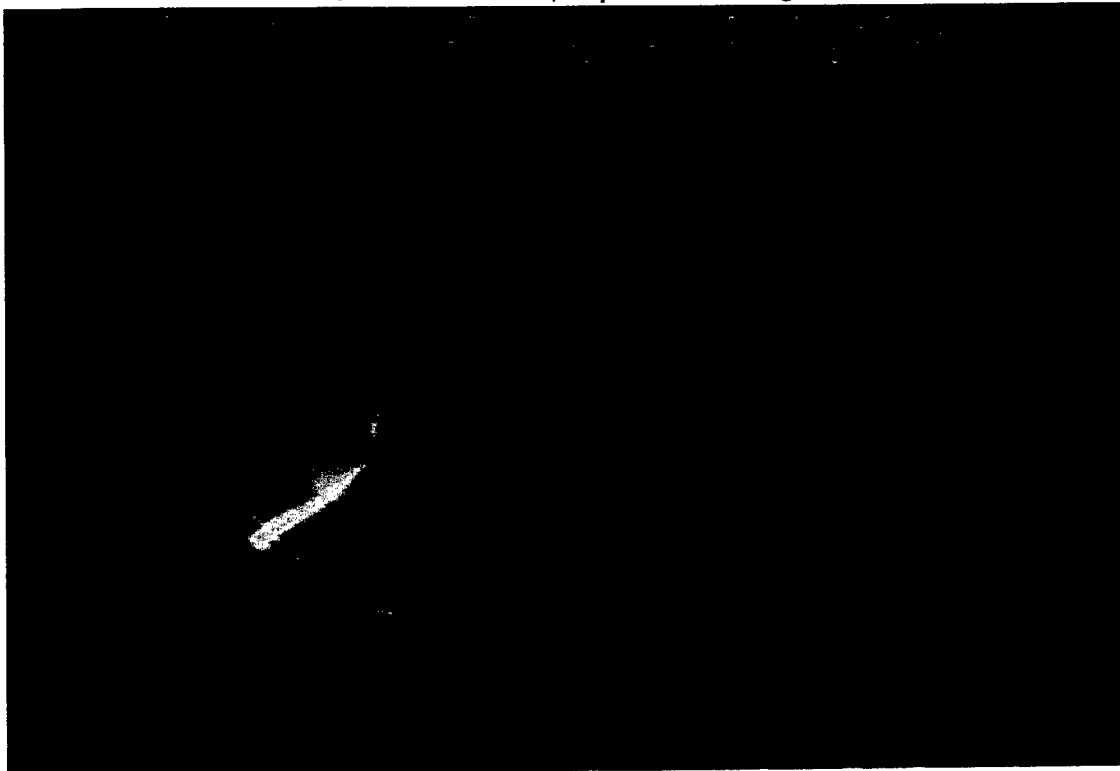


Sheet Position 3, Alpha = 29.54 deg

Figure 6.28 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 29.52 deg



Sheet Position 14, $\alpha = 29.56^\circ$



Sweeping Sheet, $\alpha = 29.51^\circ$

Figure 6.28 - (Concluded)

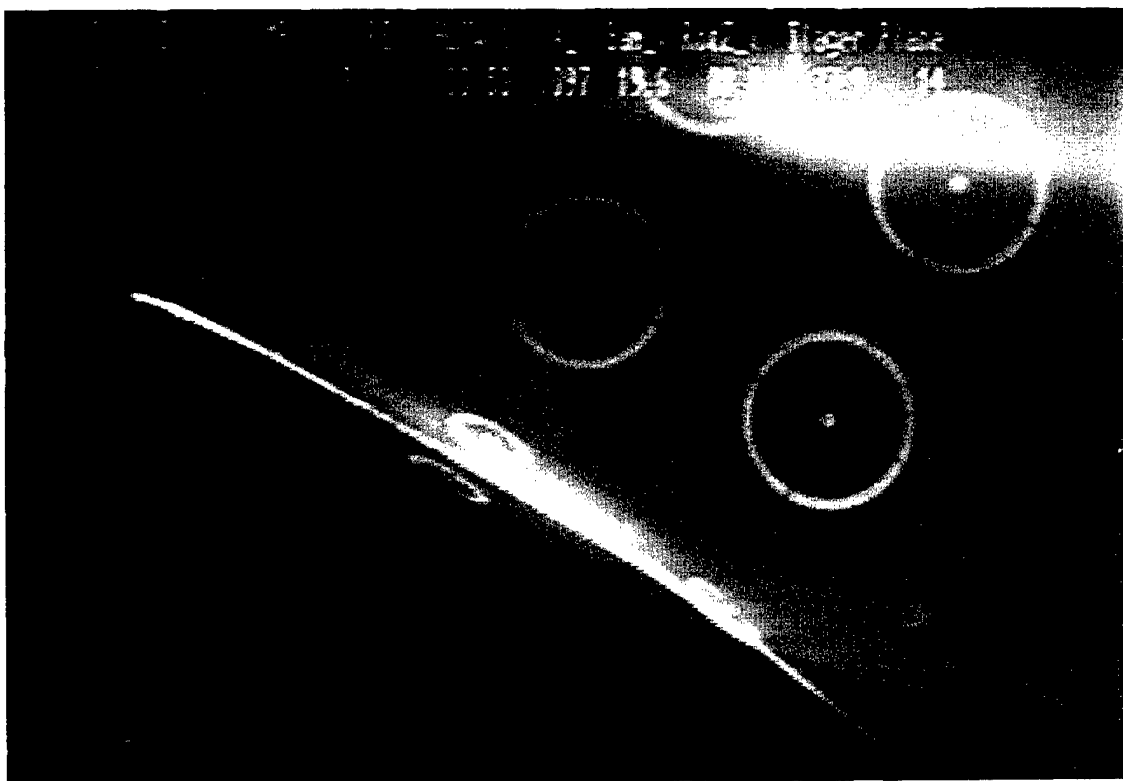


Sheet Position 1, Alpha = 30.55 deg



Sheet Position 3, Alpha = 30.57 deg

Figure 6.29 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, $\alpha = 30.56^\circ$

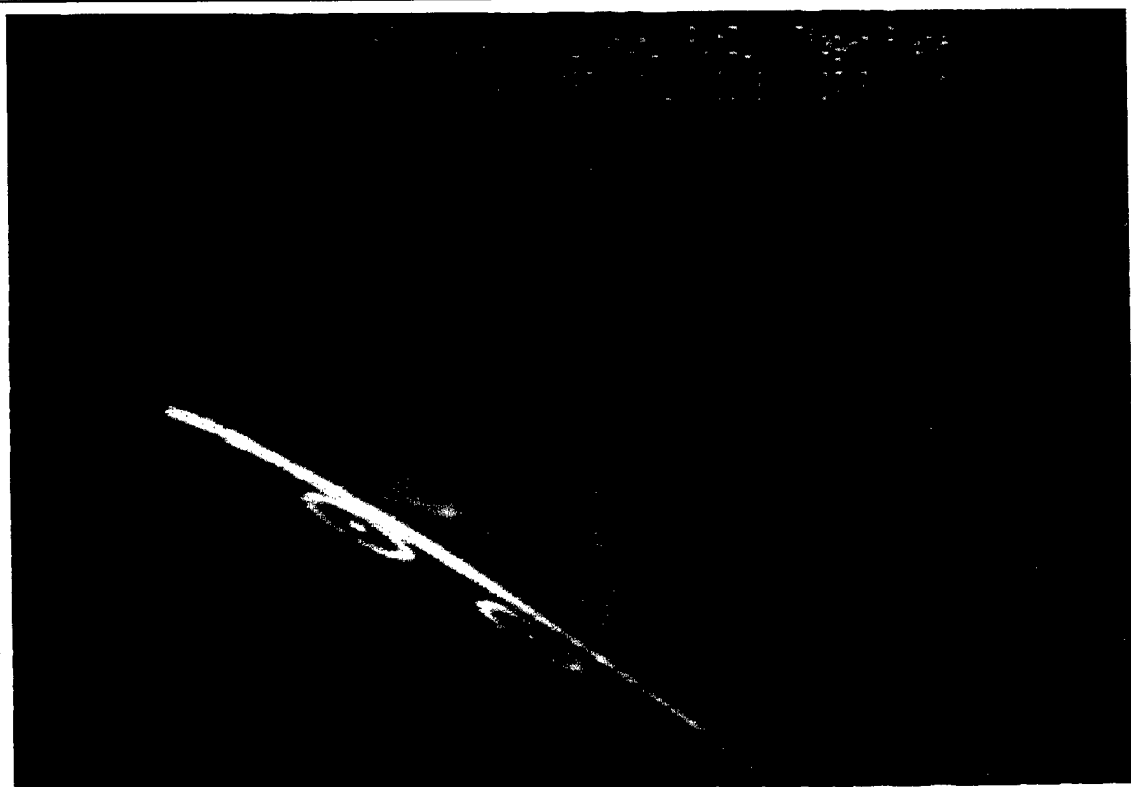


Sheet Position 14, $\alpha = 30.50^\circ$



Sweeping Sheet, $\alpha = 30.55^\circ$

Figure 6.29 - (Concluded)

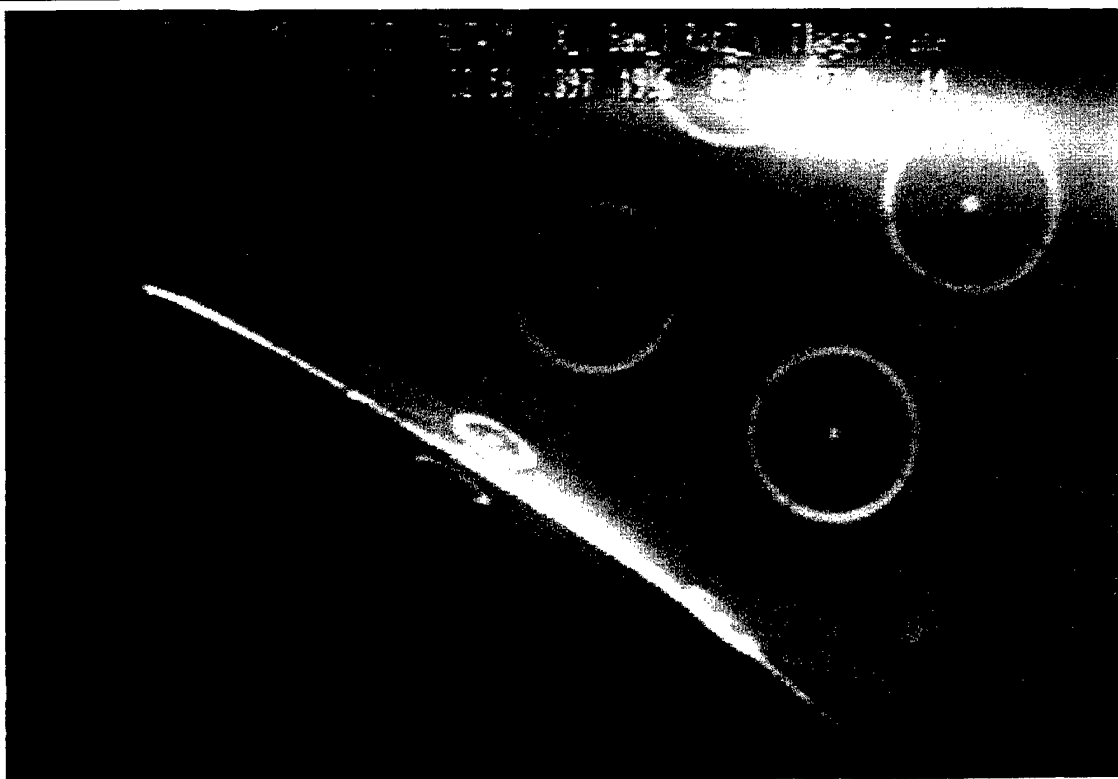


Sheet Position 1, Alpha = 32.49 deg



Sheet Position 3, Alpha = 32.52 deg

Figure 6.30 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 32.51 deg

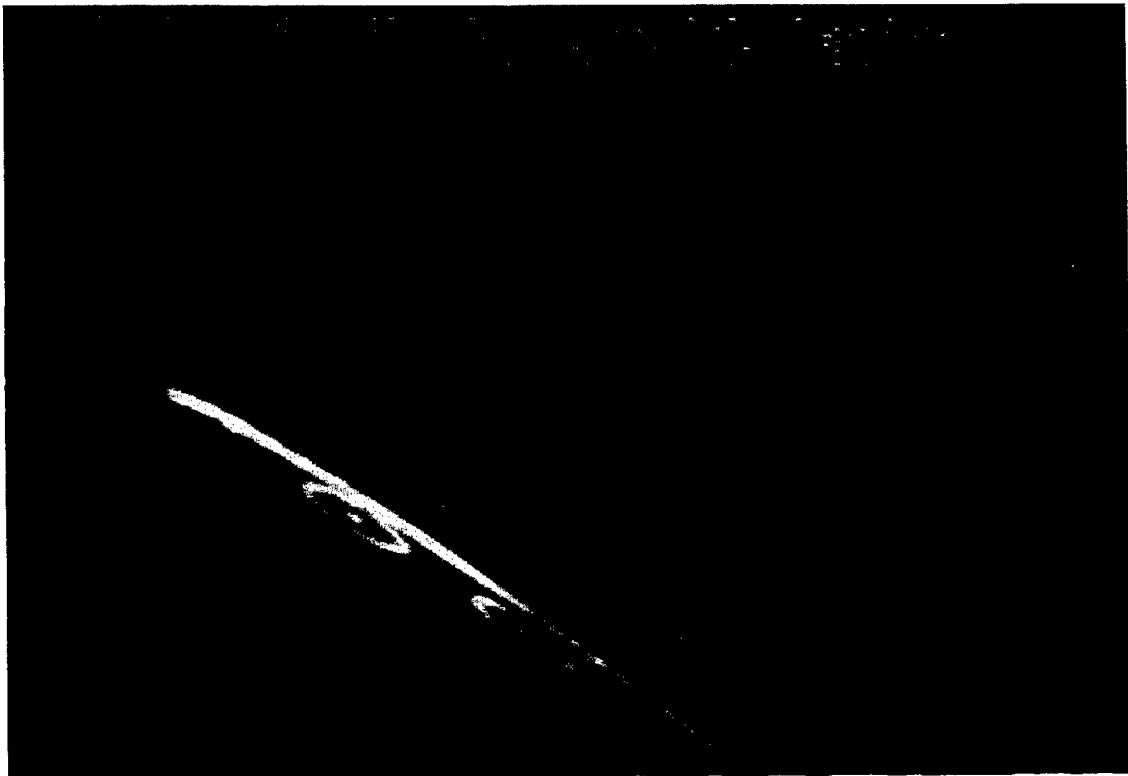


Sheet Position 14, $\alpha = 32.56^\circ$

NO DATA

Sweeping Sheet, $\alpha = 32.56^\circ$

Figure 6.30 - (Concluded)

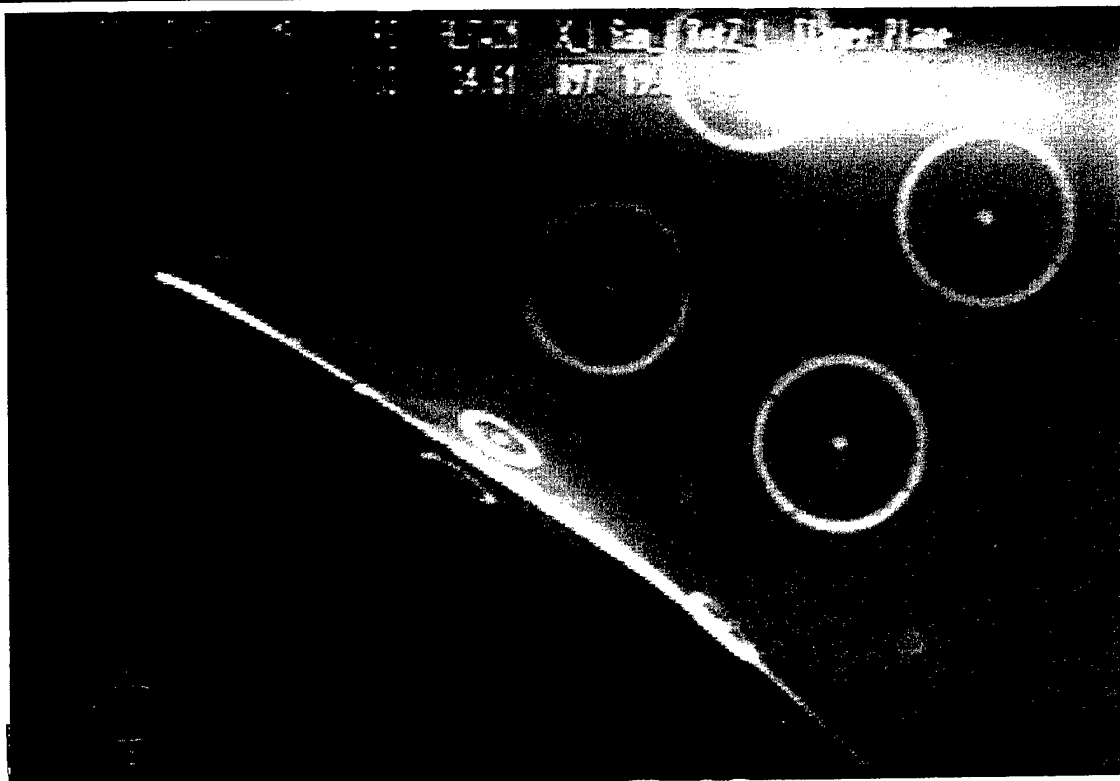


Sheet Position 1, Alpha = 34.62 deg



Sheet Position 3, Alpha = 34.40 deg

Figure 6.31 - Side View Camera of Streamwise Laser Light Sheet at Various Positions, $M = 0.9$, Alpha = 34.51 deg



Sheet Position 14, $\alpha = 34.61$ deg

NO DATA

Sweeping Sheet, $\alpha = 34.61$ deg

Figure 6.31 - (Concluded)

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4.0 SIDE VIEW OF PULSED LASER SHEET FOR THE CLEAN WING AT $M = 0.9$, $\alpha = 6$ DEG TO 22 DEG

A pulsed laser sheet with a duration of 9 nano-seconds was used at sheet position 3, as shown below in Figure 7. Selected angles were chosen in order to highlight various flow transition conditions. Although frame rates were limited to 10 frames per second, the high resolution of 1000 x 1000 pixels, and very short exposure time, provided excellent detail of the highly turbulent nature of separated transonic flows. In addition, image enhancement software was used to bring out even more detail, much of which is not understood at this time. These data are shown in Figures 8.01 through 8.21 where, in several cases, multiple shots are shown for the same condition to emphasize natural unsteadiness of the separated flows.

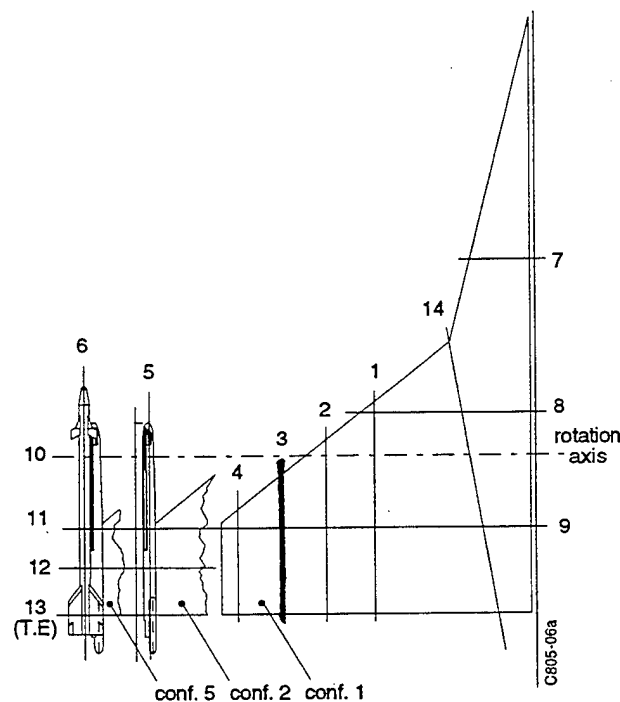
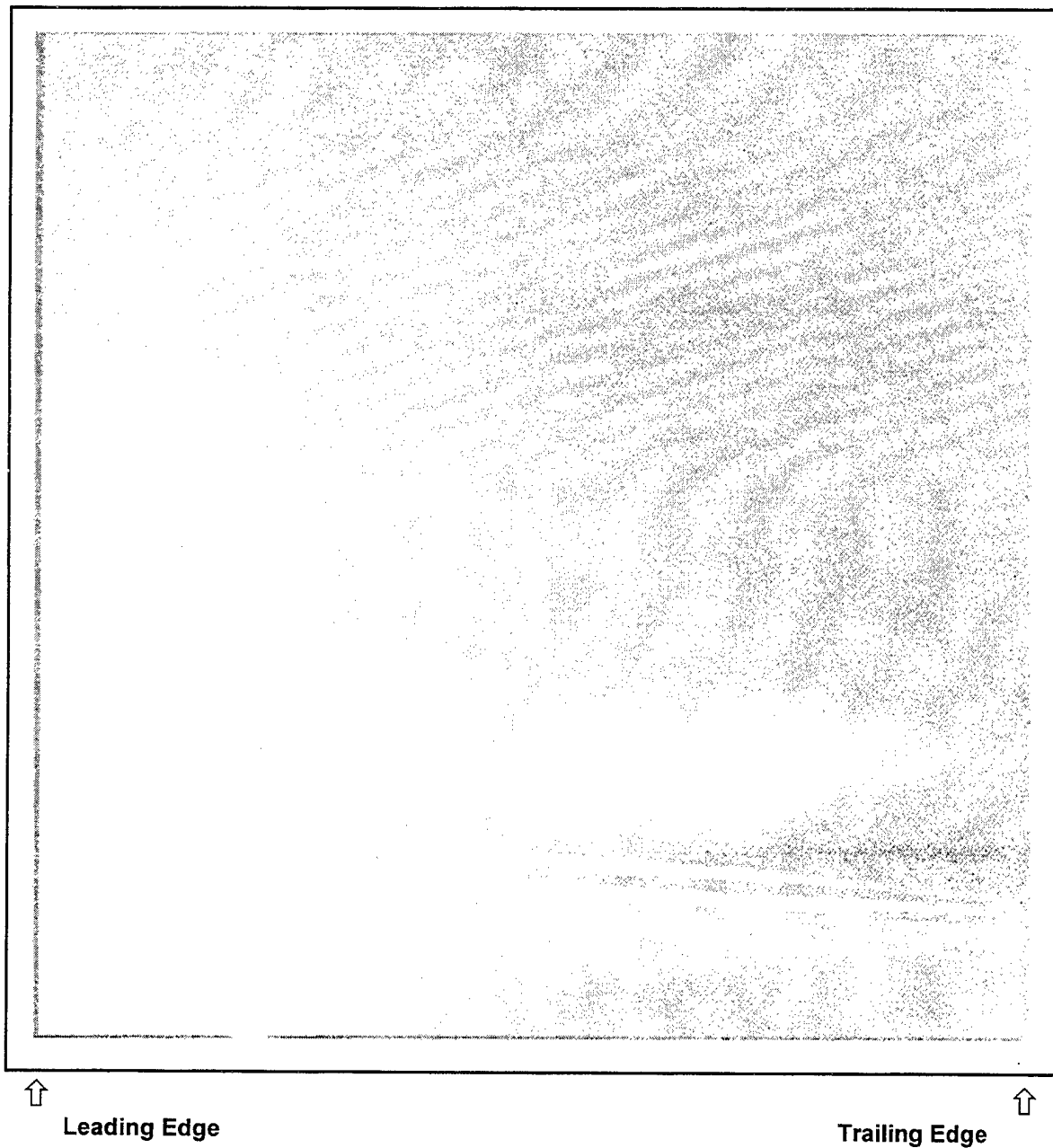
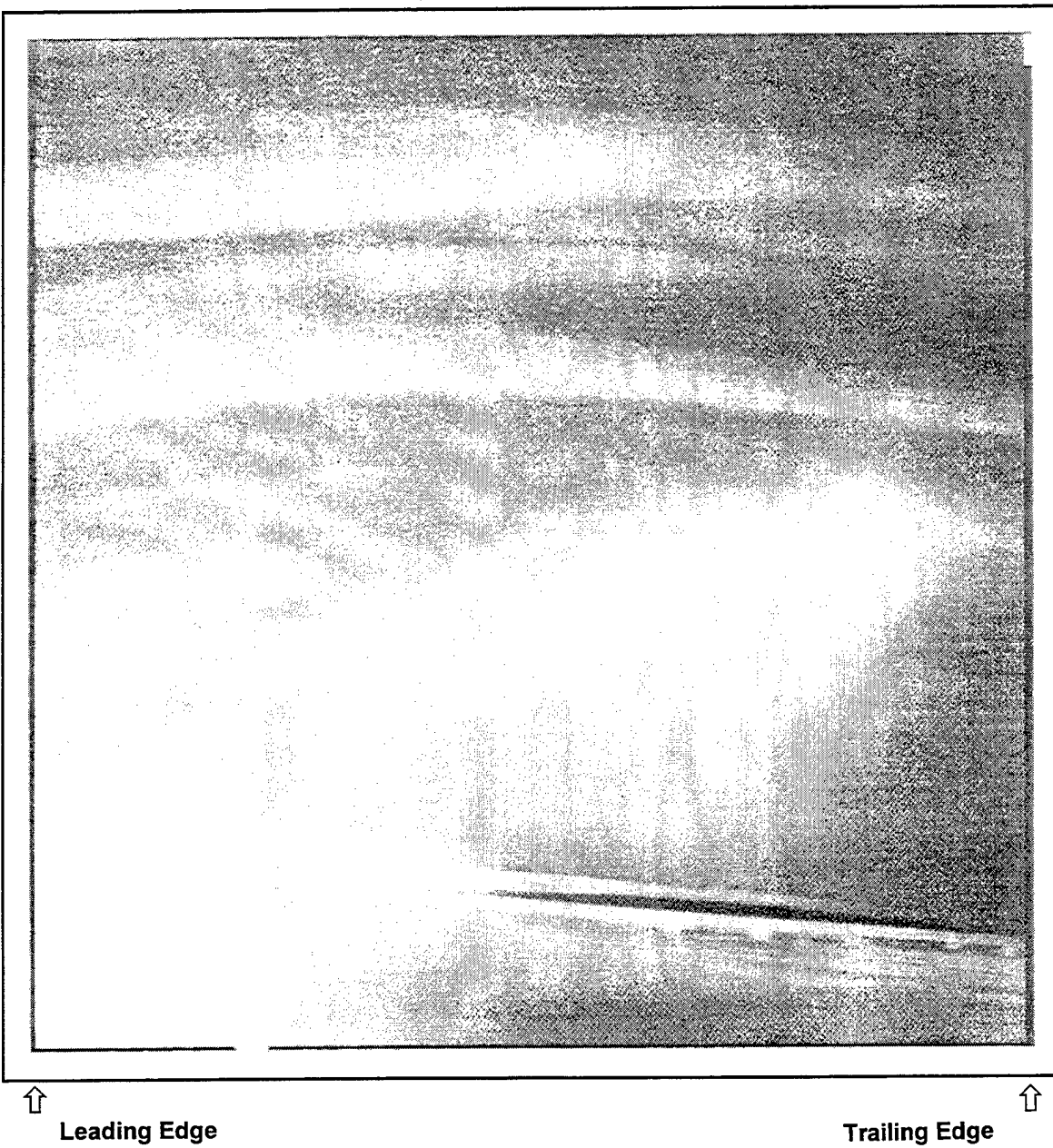


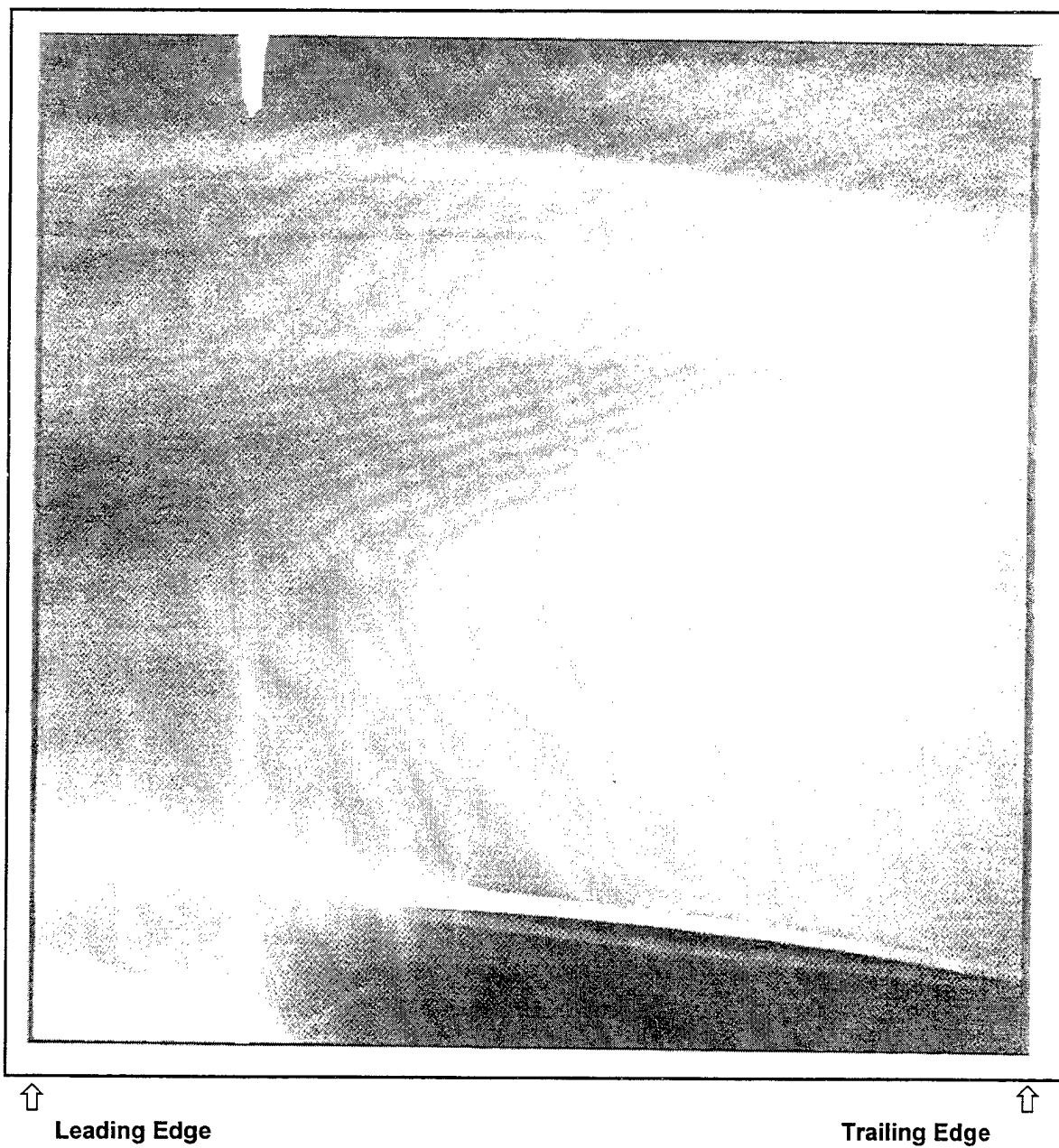
Figure 7 - Pulsed Laser Sheet Locations for Figures 8, Clean Wing, $M = 0.9$, $\alpha = 6$ deg to 22 deg



**Figure 8.01 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 6.0$ deg**



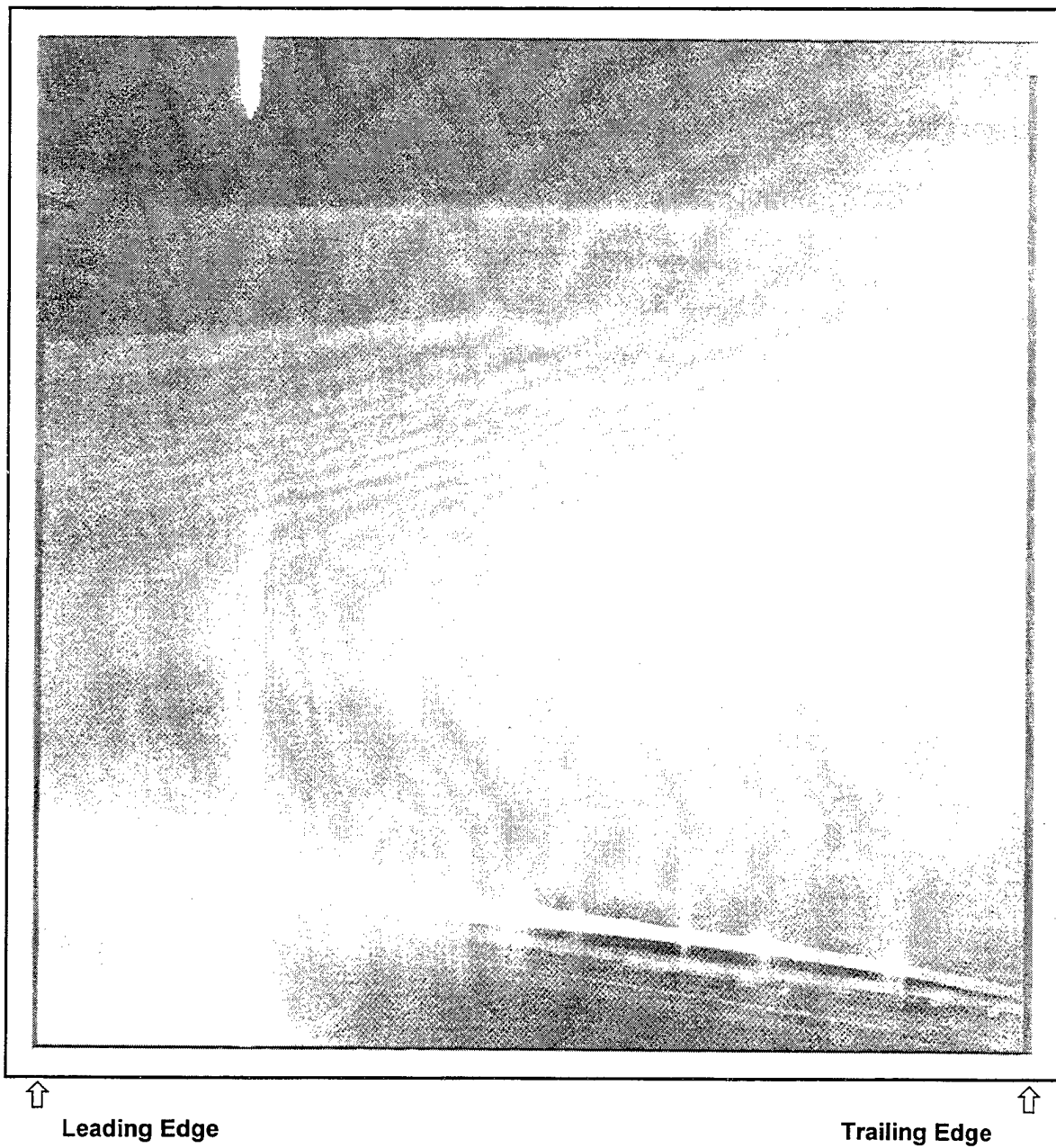
**Figure 8.02 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 8.0$ deg**



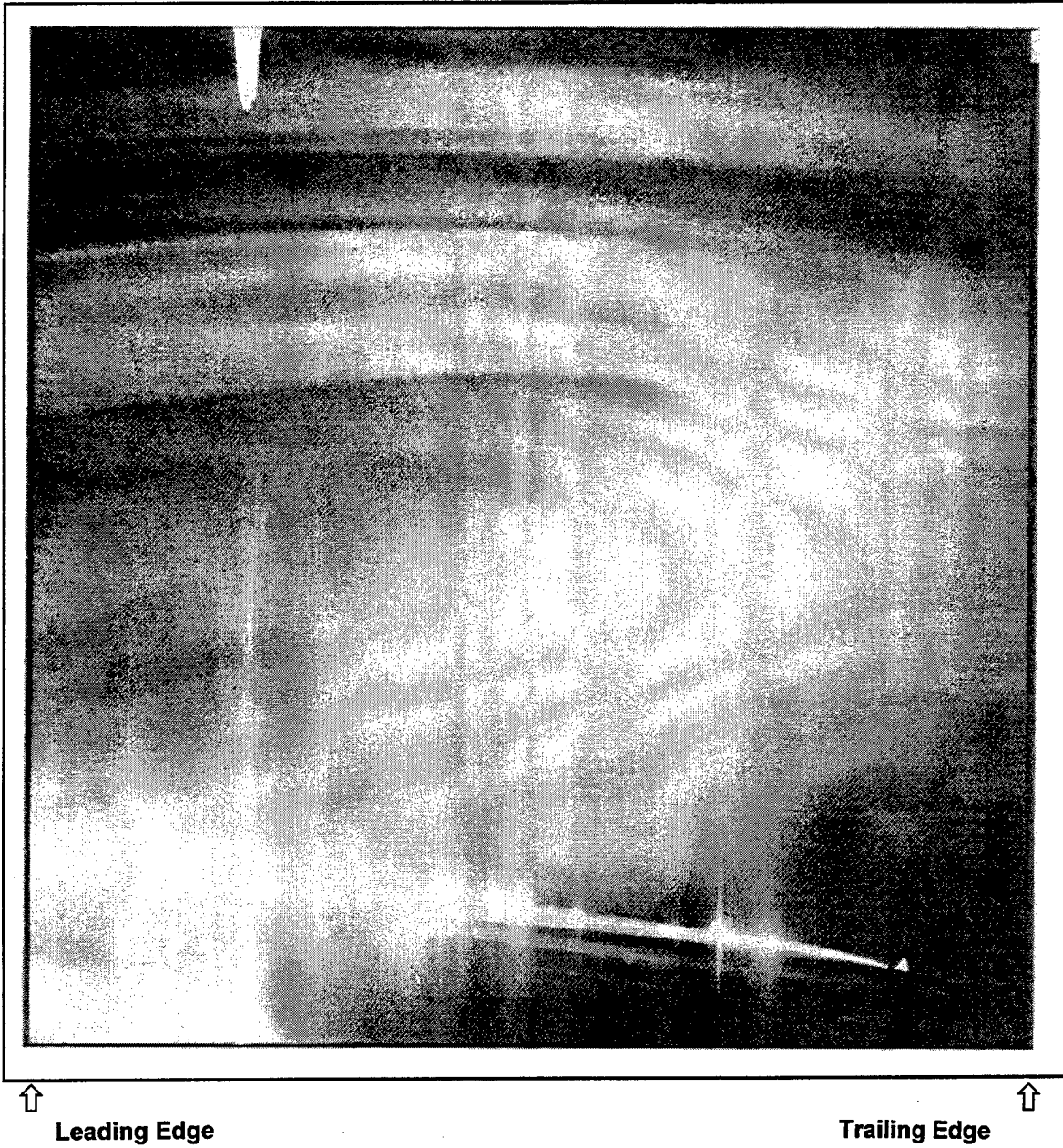
**Figure 8.03 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 10.0$ deg**



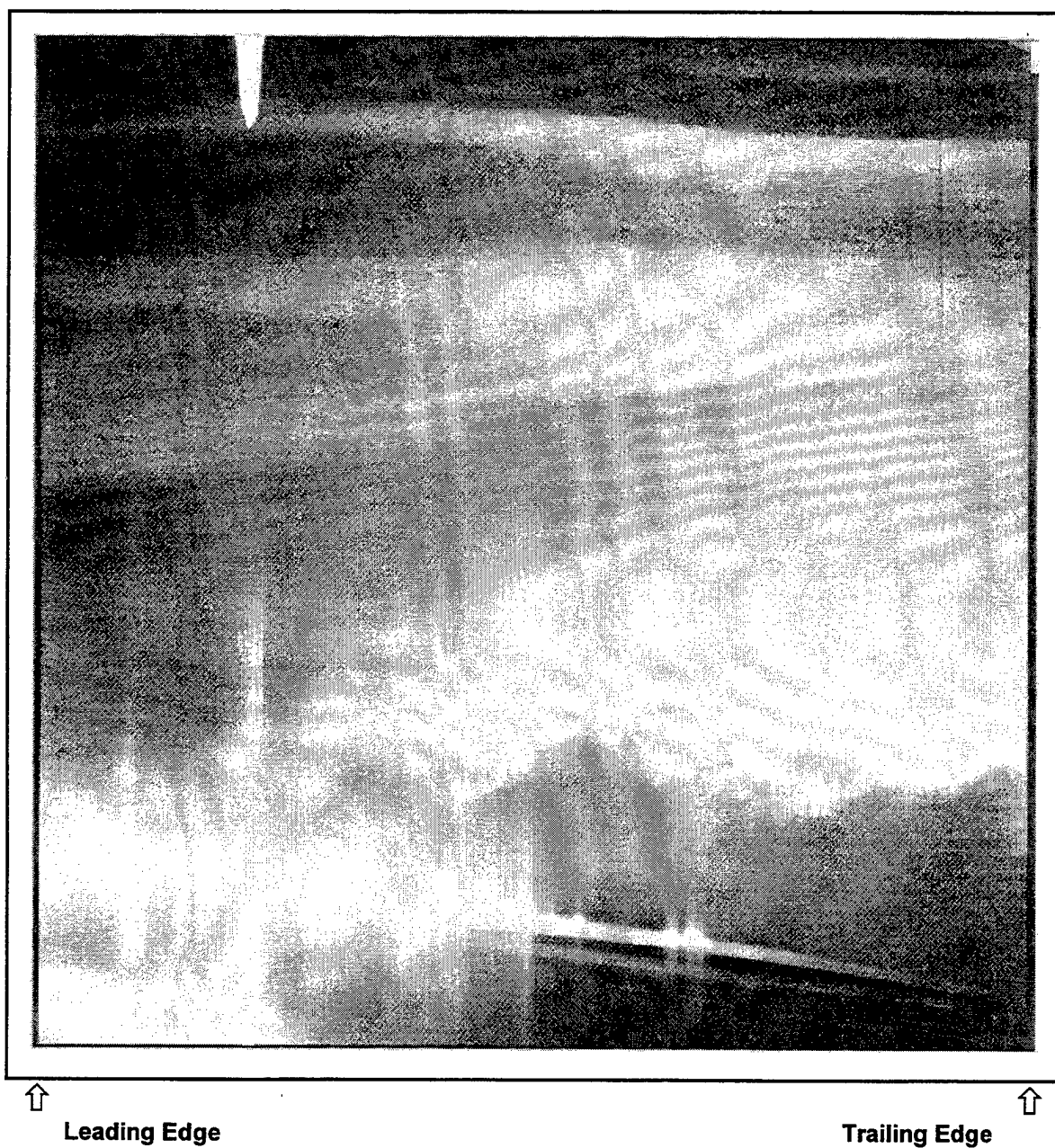
**Figure 8.04 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 10.5$ deg**



**Figure 8.05 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 10.5$ deg**



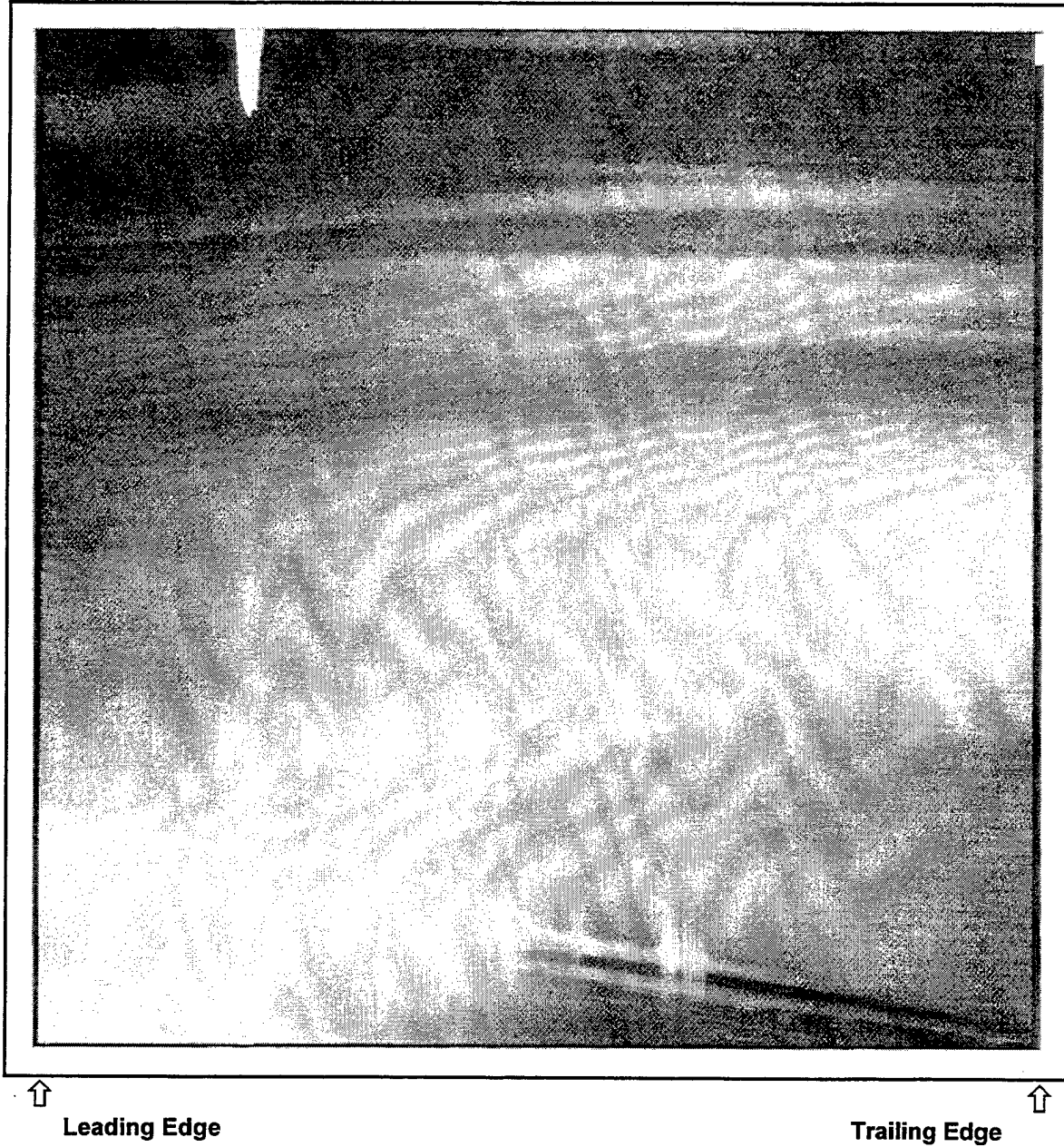
**Figure 8.06 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 10.5$ deg**



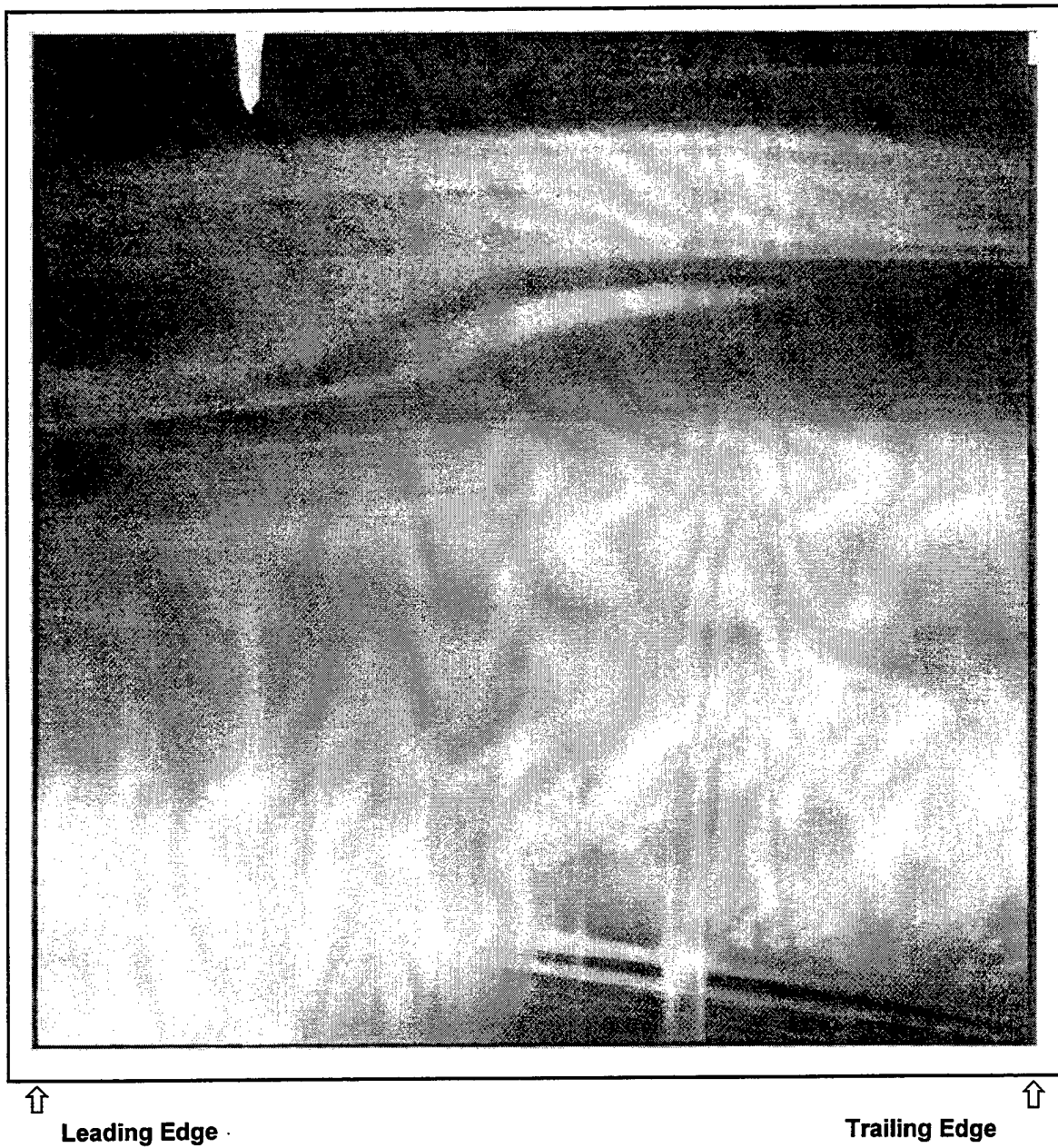
**Figure 8.07 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 11.0$ deg**



**Figure 8.08 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 11.0$ deg**



**Figure 8.09 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 12.0$ deg**



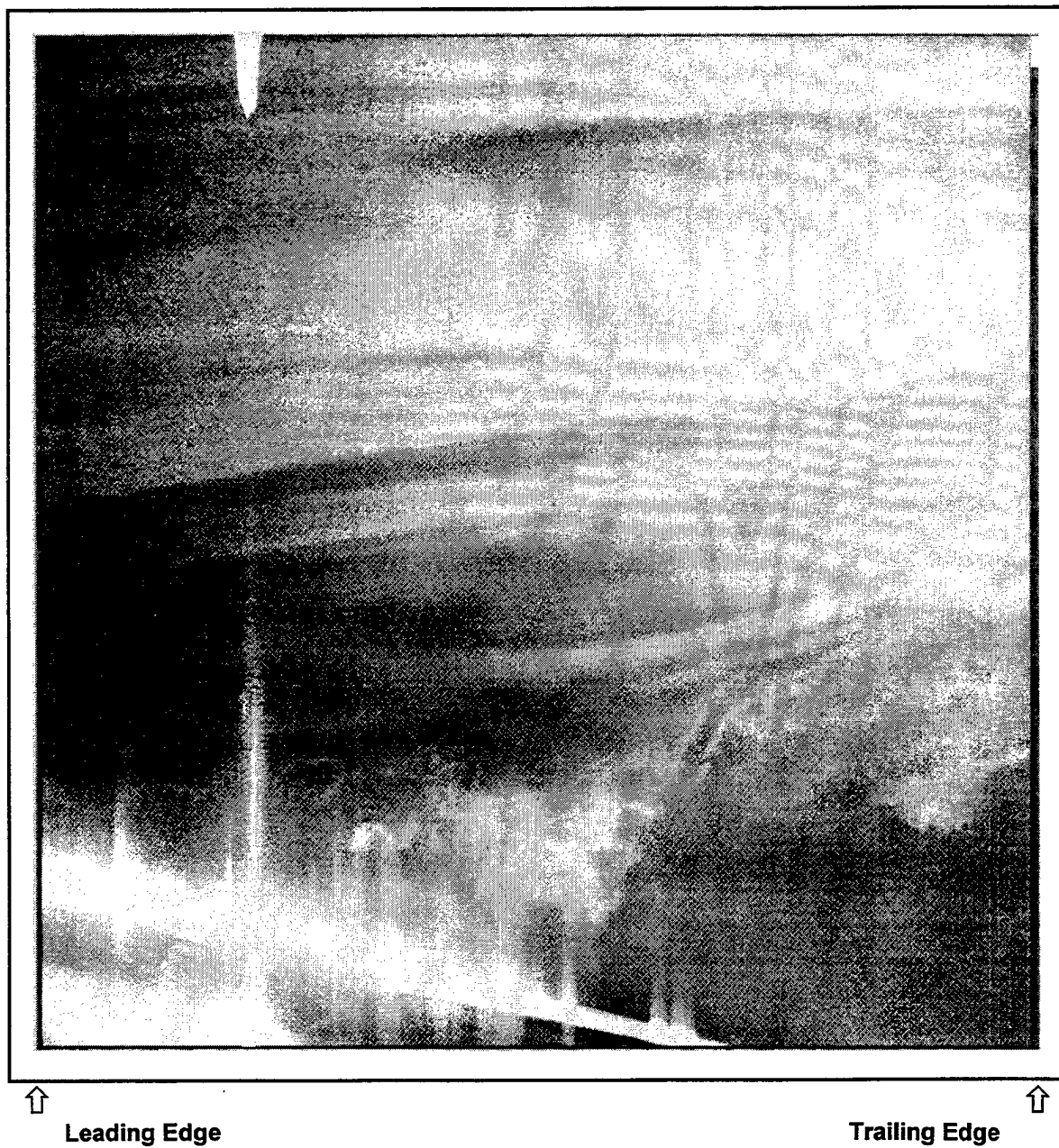
**Figure 8.10 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 12.0$ deg**



**Figure 8.11 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 17.0$ deg**



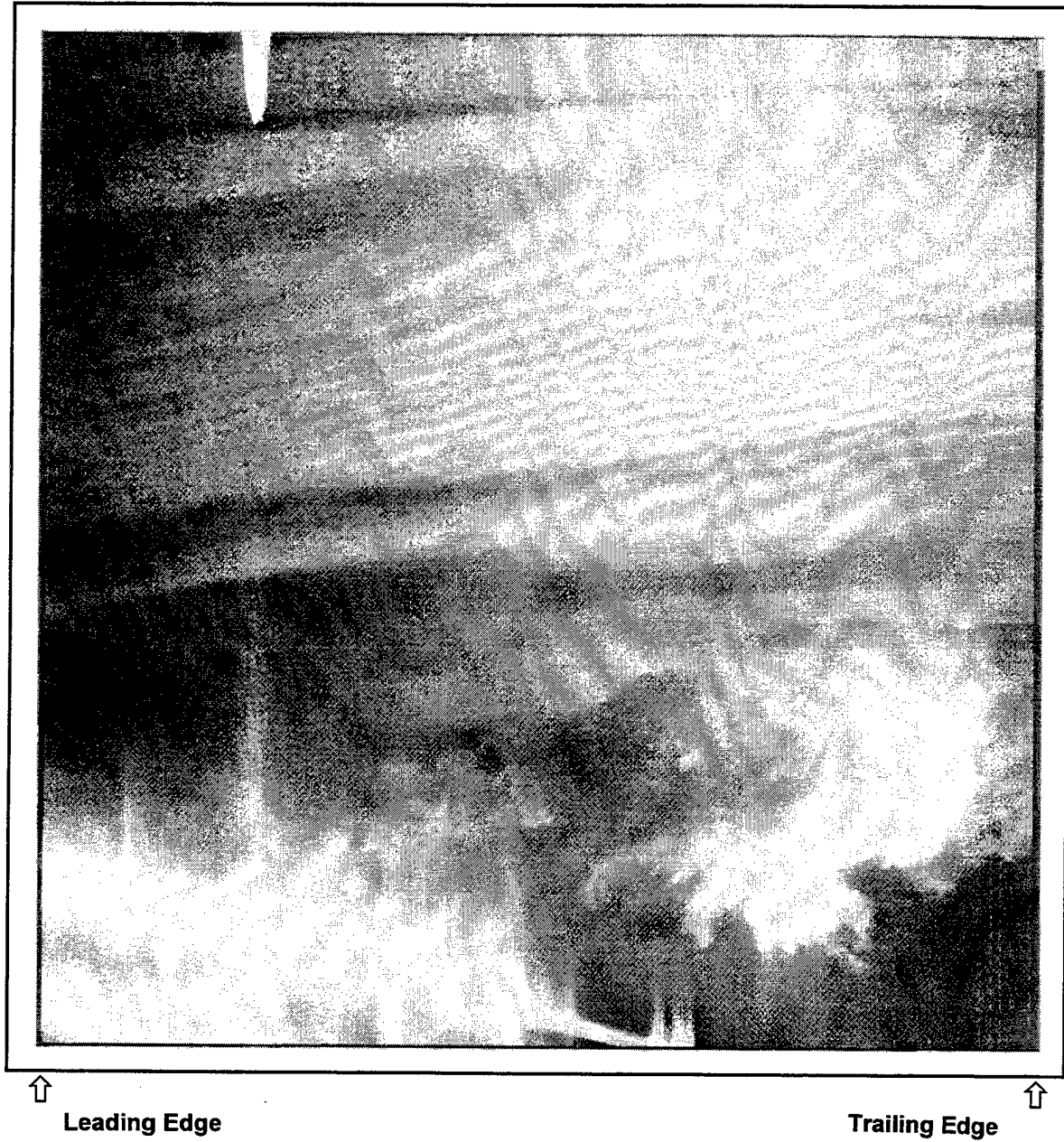
**Figure 8.12 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 17.0$ deg**



**Figure 8.13 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 17.0$ deg**



**Figure 8.14 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 18.0$ deg**



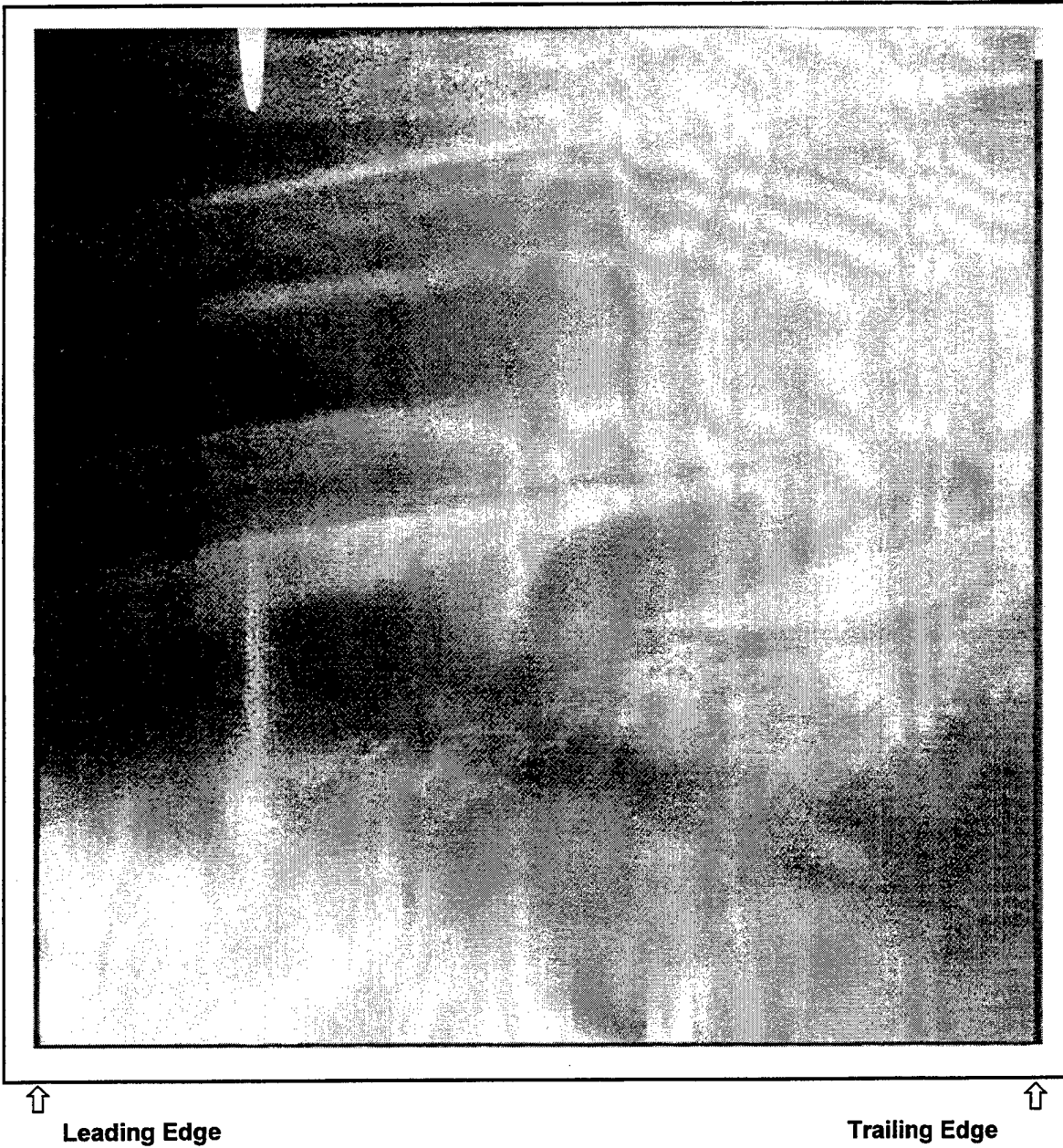
**Figure 8.15 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 18.0$ deg**



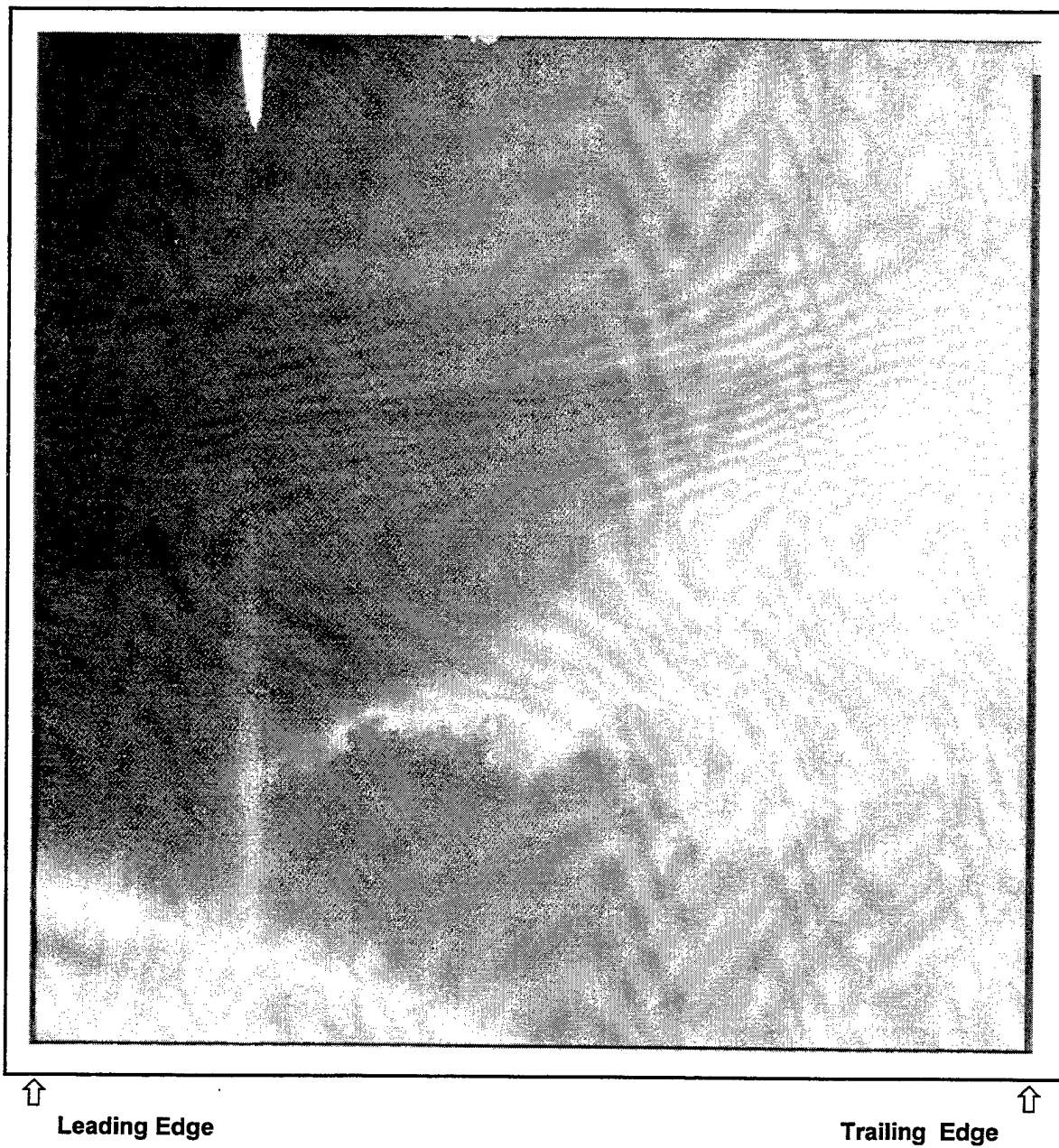
**Figure 8.16 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 19.0$ deg**



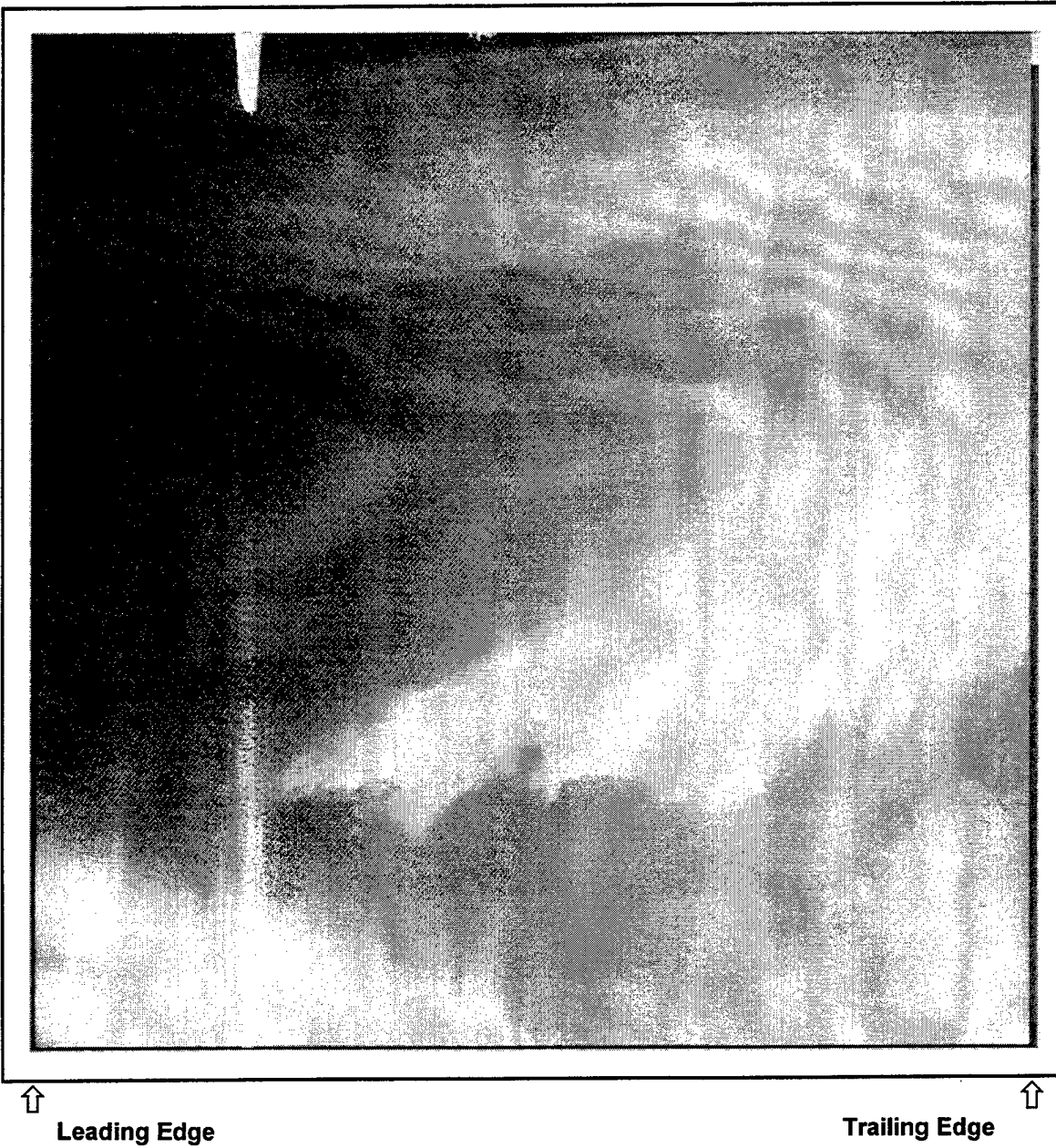
**Figure 8.17 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 19.0$ deg**



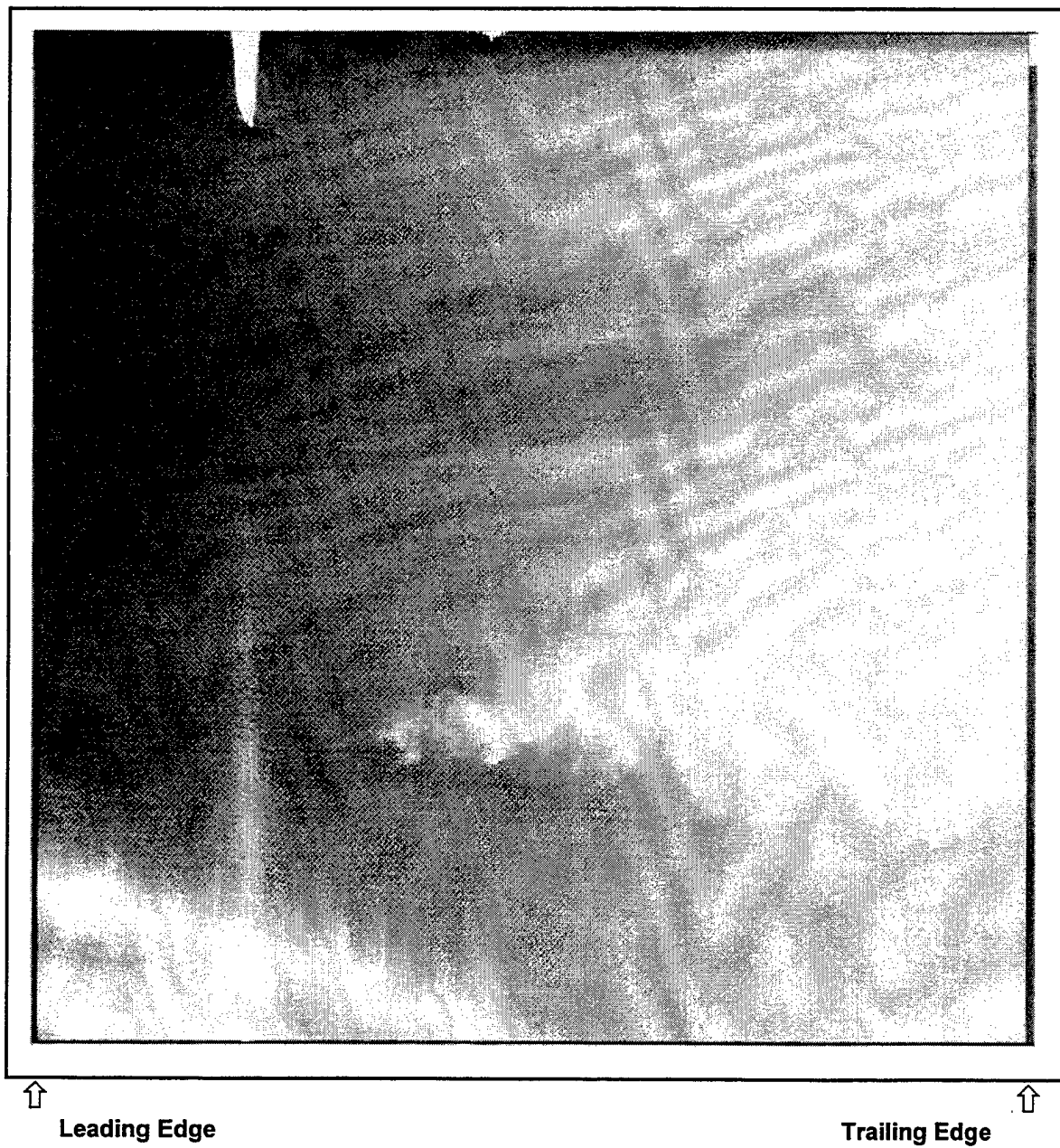
**Figure 8.18 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 19.0$ deg**



**Figure 8.19 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 22.0$ deg**



**Figure 8.20 - Pulsed Laser Recording At Sheet Position 3
(80% Span) For The Clean Wing, $M = 0.9$,
 $\alpha = 22.0$ deg**



**Figure 8.21 - Pulsed Laser Recording At Sheet Position 3
(80% Span) for the Clean Wing, $M = 0.9$,
 $\alpha = 22.0$ deg**

5.0 HIGH SPEED VIDEO LCO FLOW VISUALIZATION FOR THE CLEAN WING AND TIP MISSILE CONFIGURATIONS AT $M = 0.9$

Individual frames from the high speed video data base for LCO-type conditions are presented in this section for three spanwise sheet positions 11, 12, and 13, as shown in Figure 9, below. (Note: Position 11 is the same as 9, except that it is focused on the outer wing panel). The frame rate was 576 frames per second, which was synchronized to give 16 frames per cycle at 36Hz. These data are available on the high speed video VHS tape and selected frames in the digital data base (see Reference 2). The data shown in this section in Figures 10.01 through 10.09 are from the digital data base. They were selected to highlight the development of flow field differences between the clean wing and wing with tip missile at $M = 0.9$.

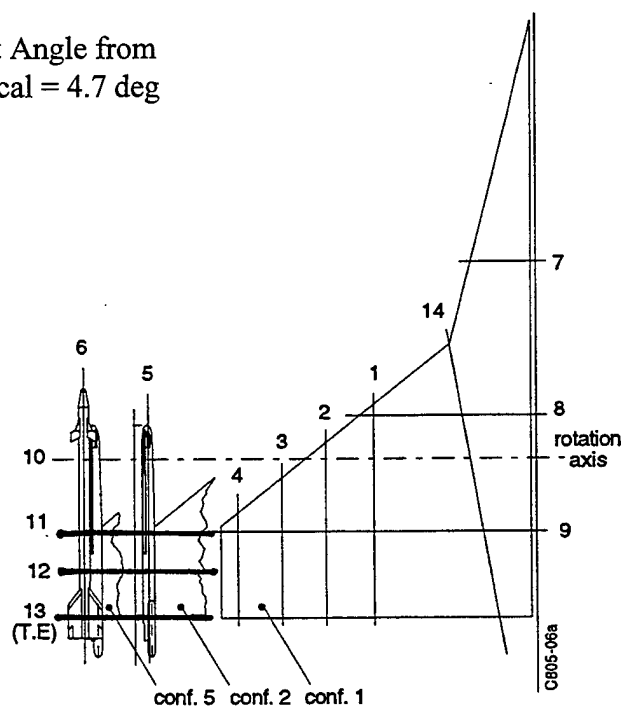
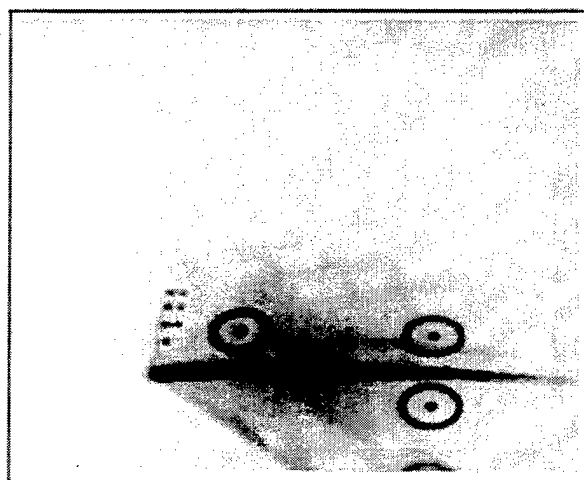
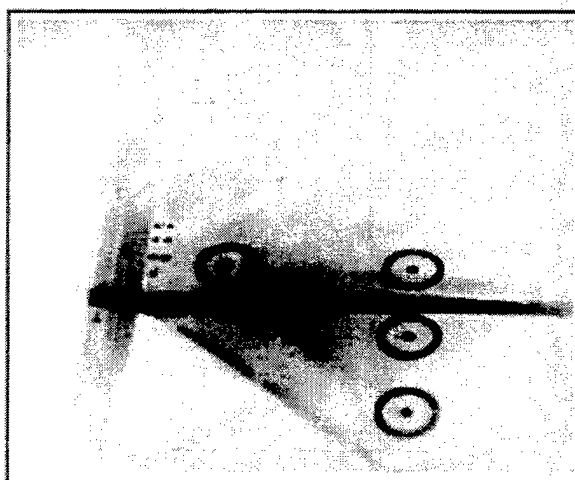


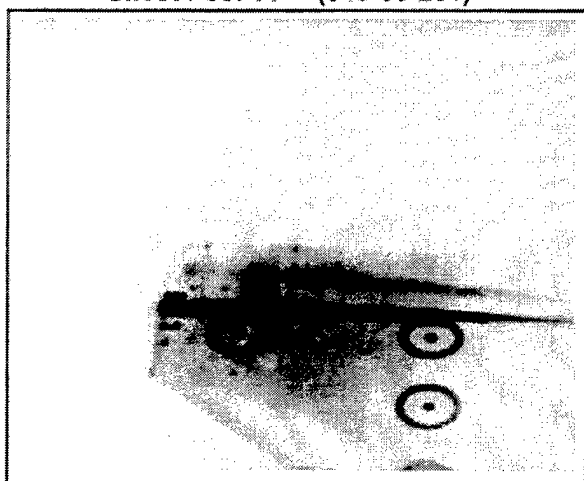
Figure 9 - Flow Visualization Locations for Figures 10, LCO Conditions, Wing With/Without Tip Missile, $M = 0.9$



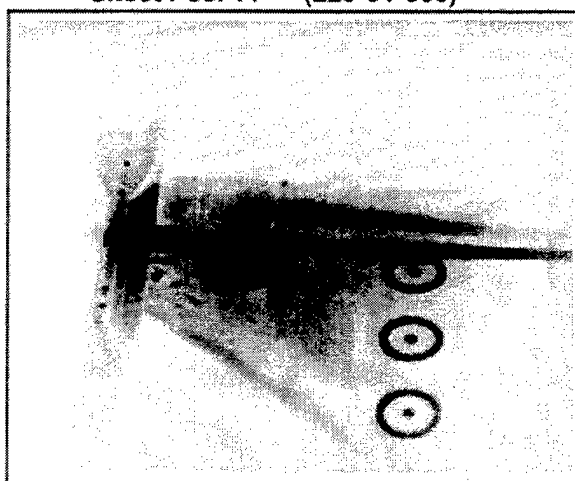
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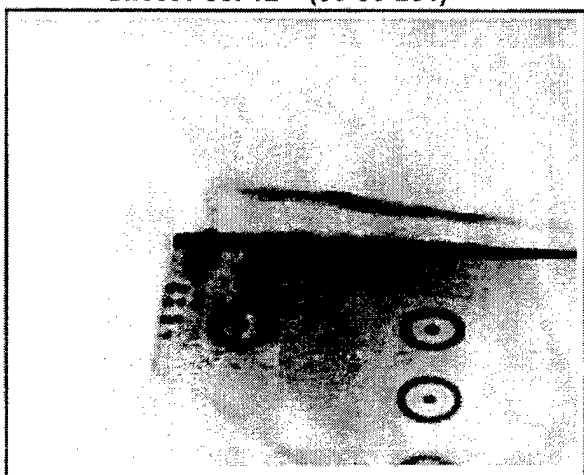
Sheet Pos. 11 (226-51-550)



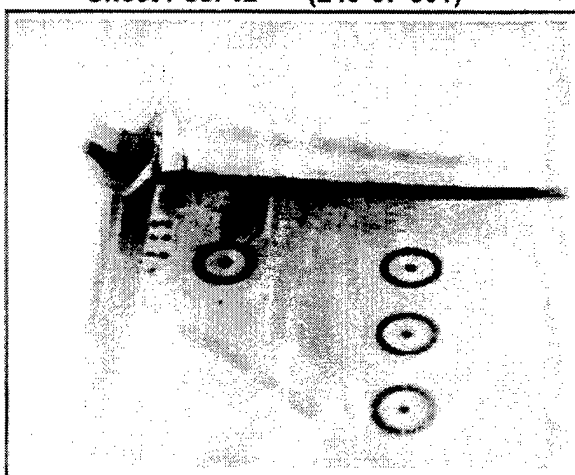
Sheet Pos. 12 (56-56-201)



Sheet Pos. 12 (240-67-301)



Sheet Pos. 13 (323-18-505)

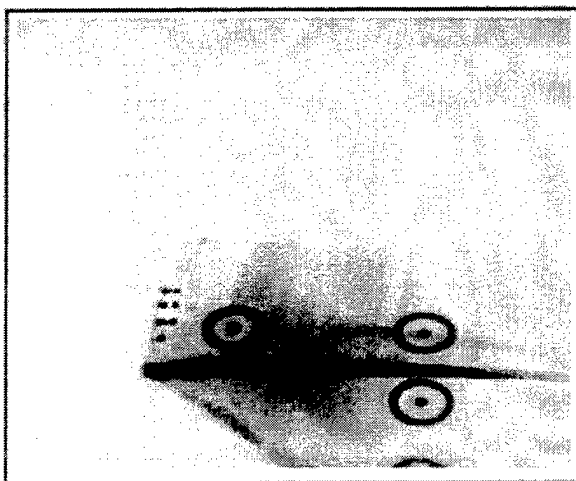


Sheet Pos. 13 (225-82-960)

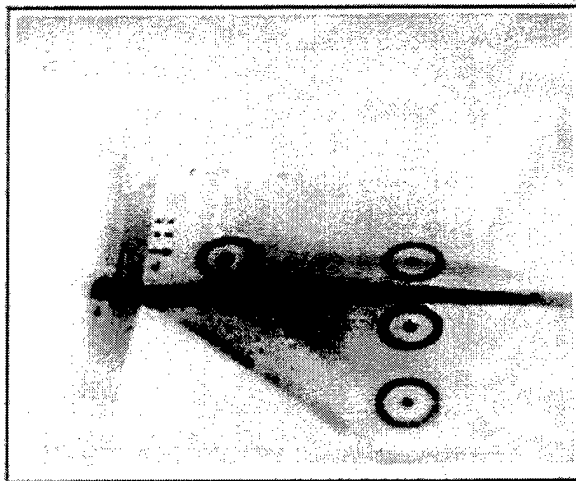
Clean Wing

Wing Tip Missile/Launcher

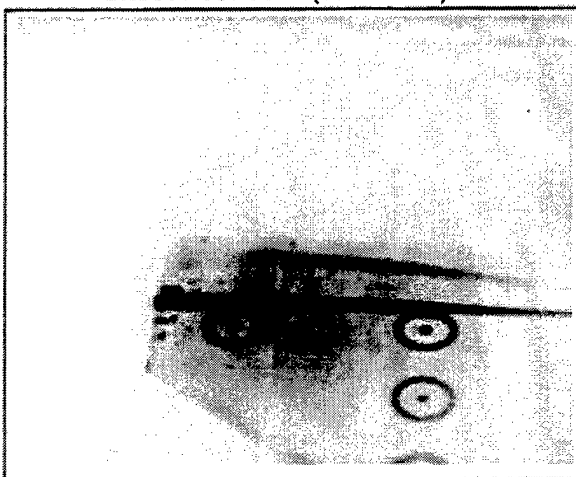
Figure 10.01 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 6.5$ deg



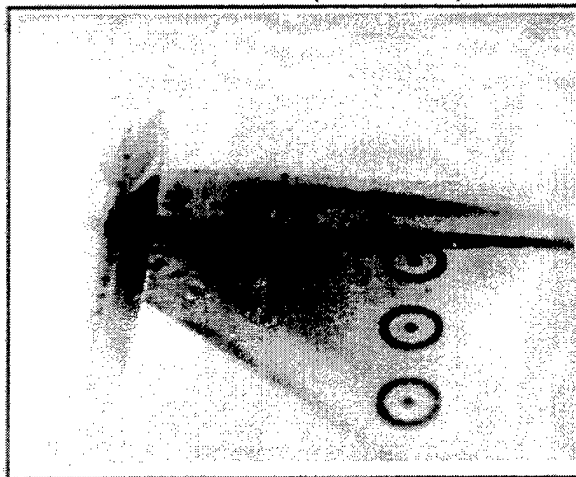
Sheet Pos. 11 (37-37-201)



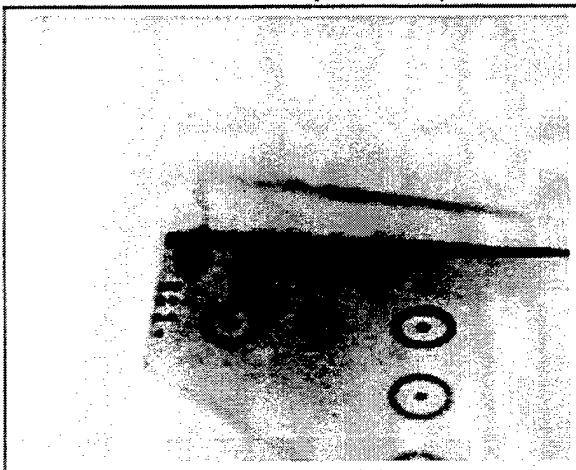
Sheet Pos. 11 (227-52-551)



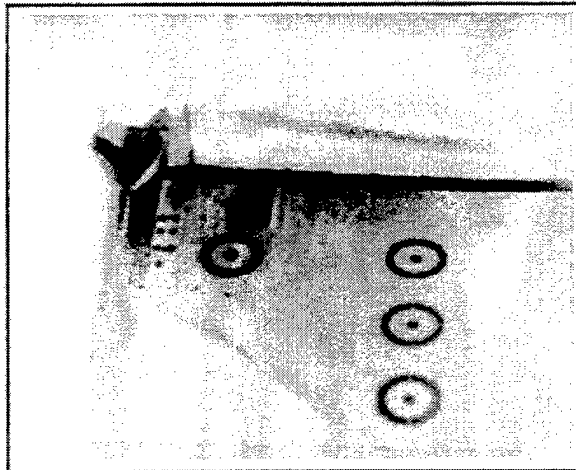
Sheet Pos. 12 (55-55-200)



Sheet Pos. 12 (241-68-999)



Sheet Pos. 13 (324-19-505)

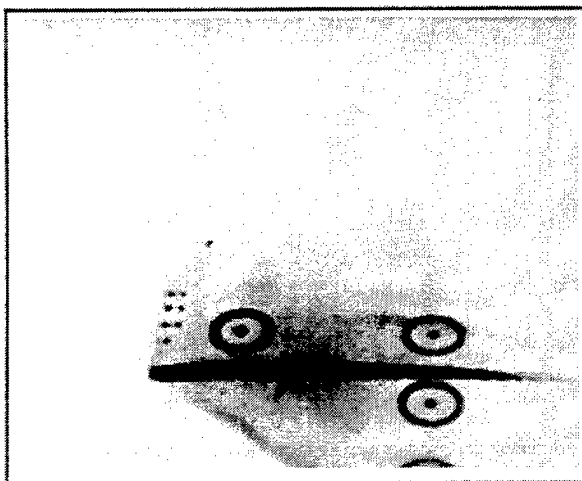


Sheet Pos. 13 (256-83-1003)

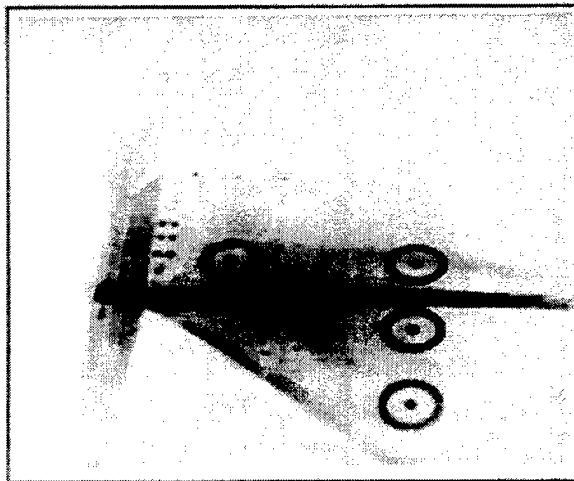
Clean Wing

Wing Tip Missile/Launcher

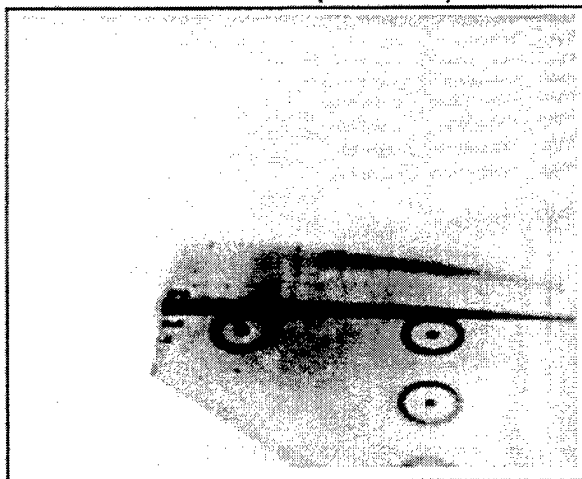
Figure 10.02 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 7.0$ deg



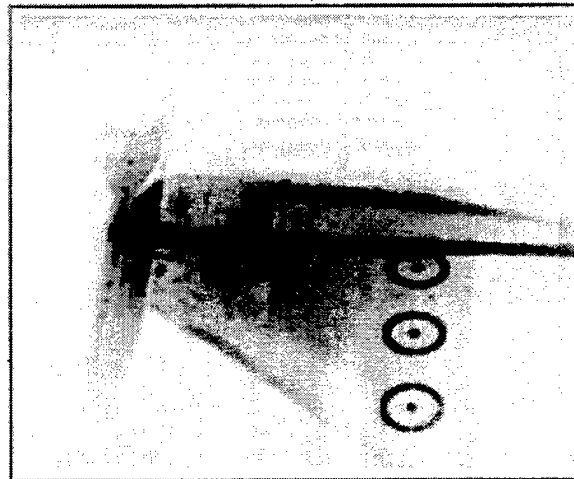
Sheet Pos. 11 (38-38-201)



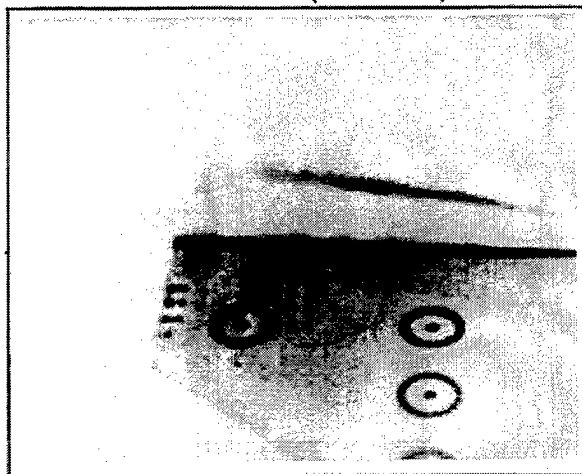
Sheet Pos. 11 (228-53-551)



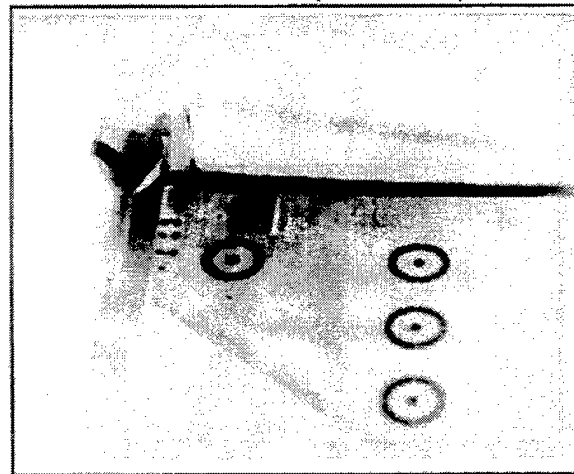
Sheet Pos. 12 (54-54-200)



Sheet Pos. 12 (242-69-351)



Sheet Pos. 13 (325-20-503)

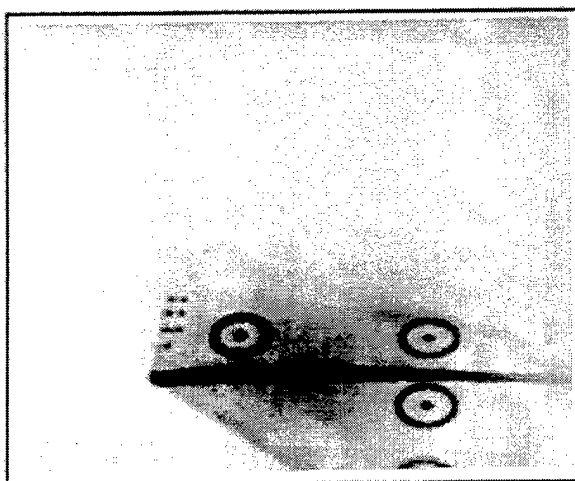


Sheet Pos. 13 (257-84-890)

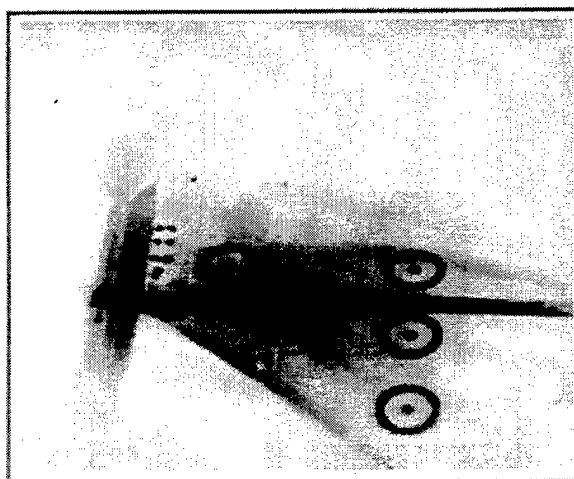
Clean Wing

Wing Tip Missile/Launcher

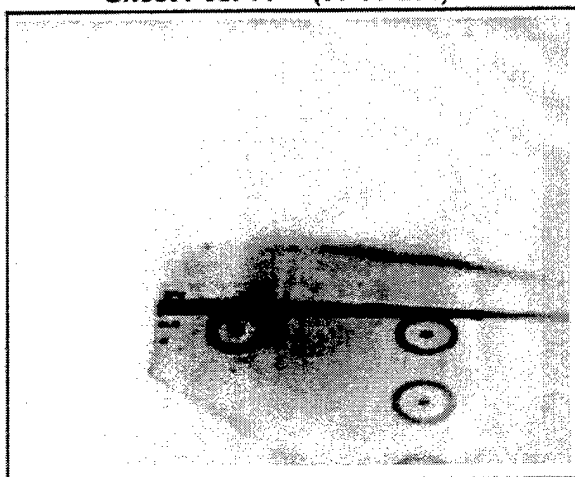
Figure 10.03 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 7.5$ deg



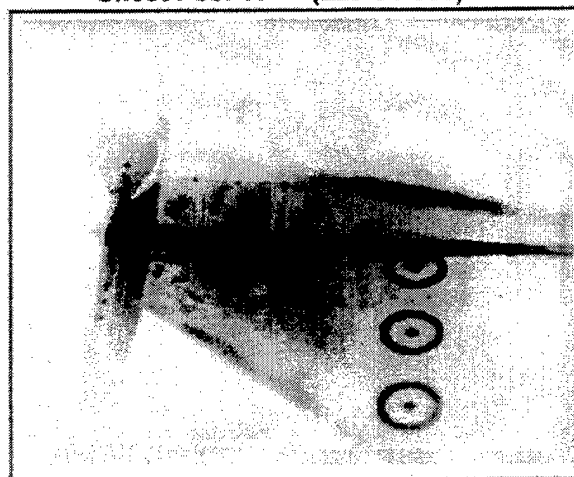
Sheet Pos. 11 (39-39-201)



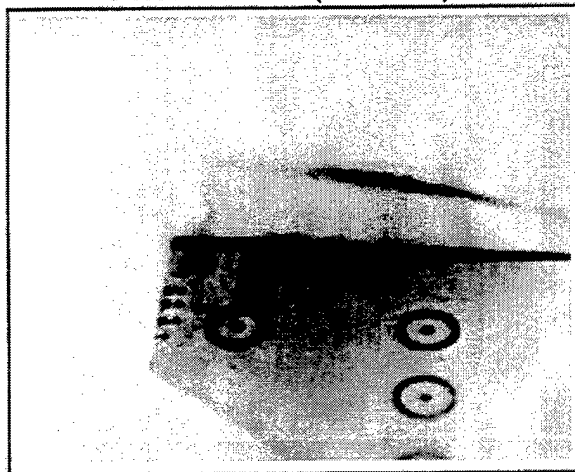
Sheet Pos. 11 (229-54-551)



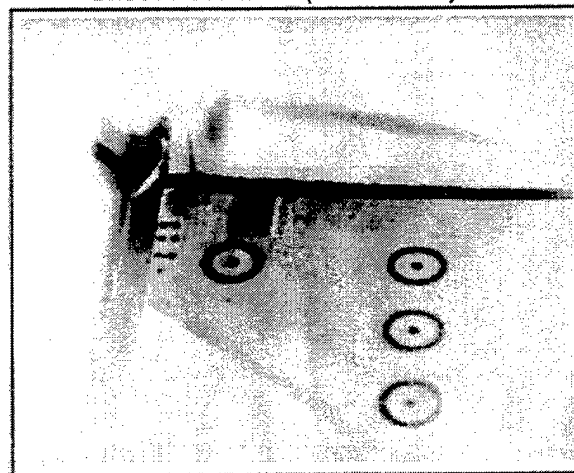
Sheet Pos. 12 (53-53-200)



Sheet Pos. 12 (243-70-604)



Sheet Pos. 13 (326-21-504)

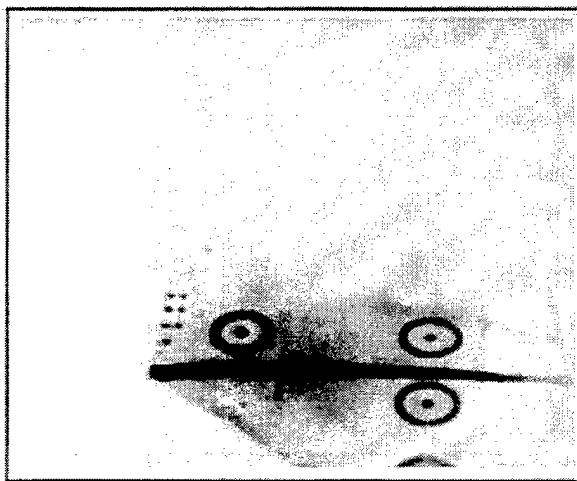


Sheet Pos. 13 (258-85-213)

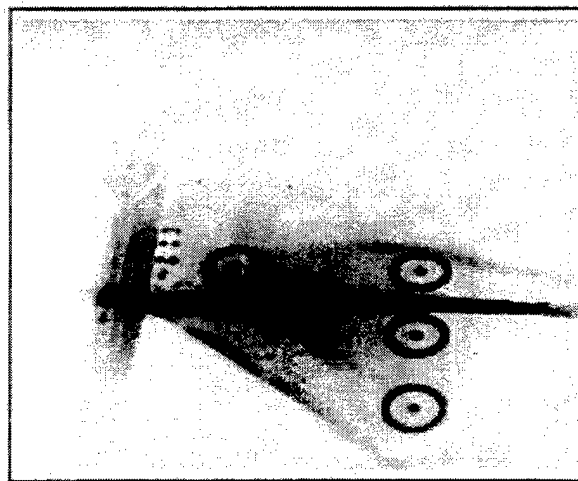
Clean Wing

Wing Tip Missile/Launcher

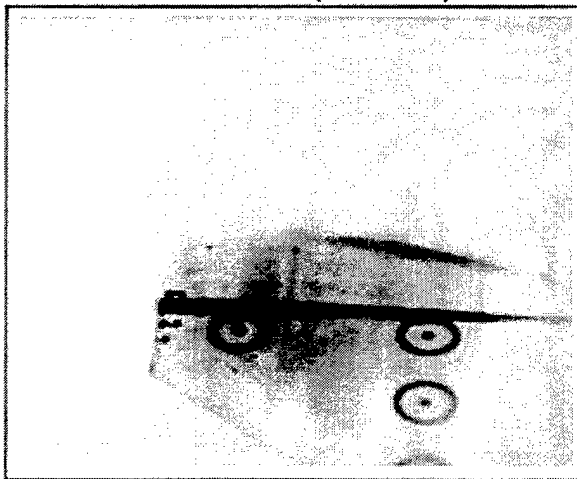
Figure 10.04 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 8.0$ deg



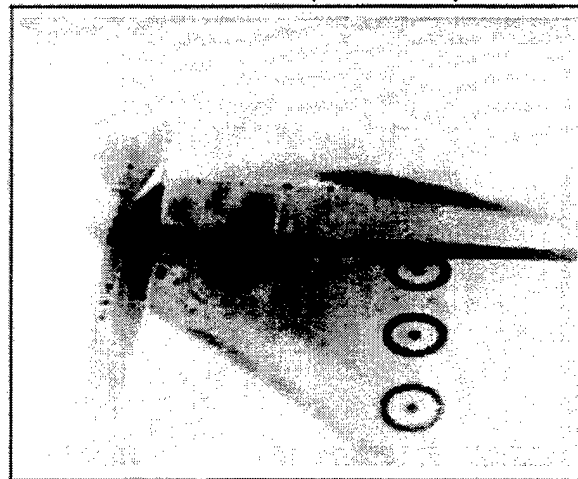
Sheet Pos. 11 (41-41-200)



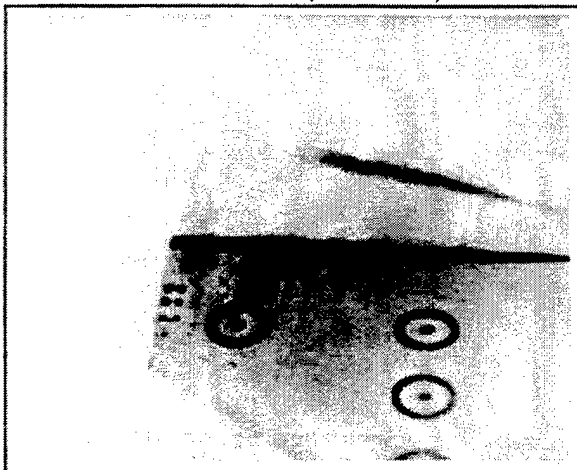
Sheet Pos. 11 (230-55-551)



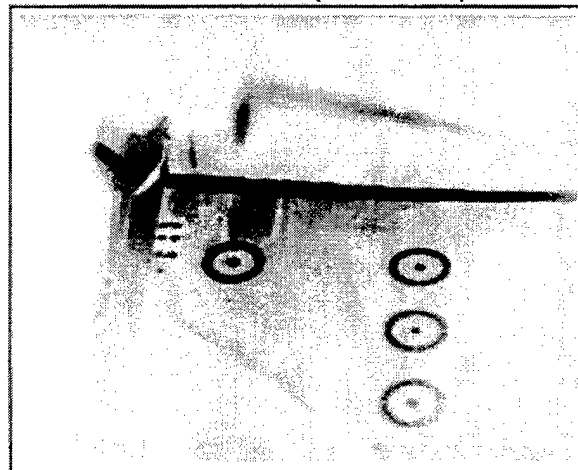
Sheet Pos. 12 (52-52-200)



Sheet Pos. 12 (244-71-446)



Sheet Pos. 13 (327-22-506)

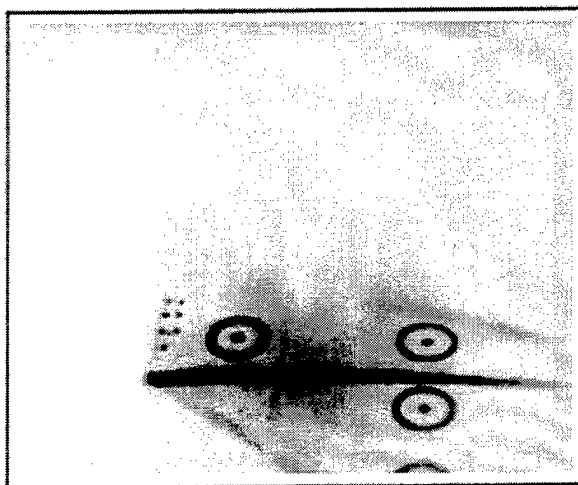


Sheet Pos. 13 (259-86-286)

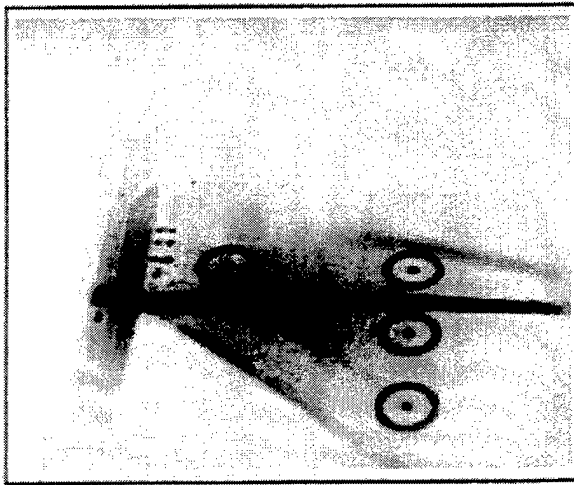
Clean Wing

Wing Tip Missile/Launcher

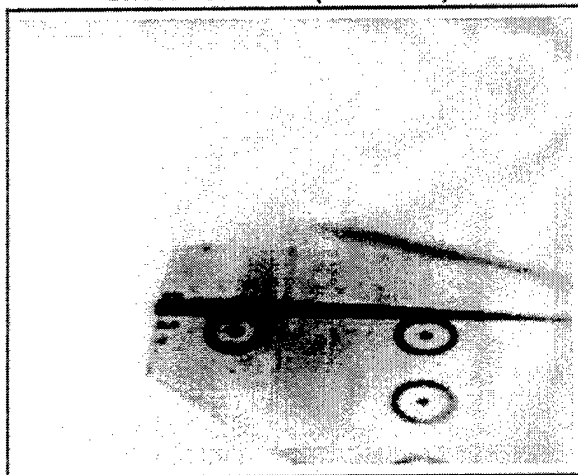
Figure 10.05 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 8.5$ deg



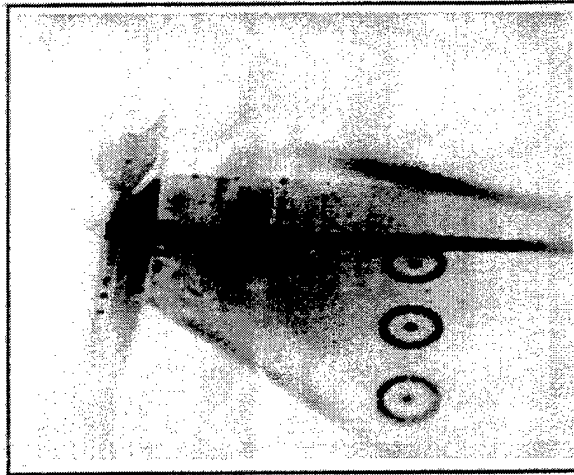
Sheet Pos. 11 (42-42-200)



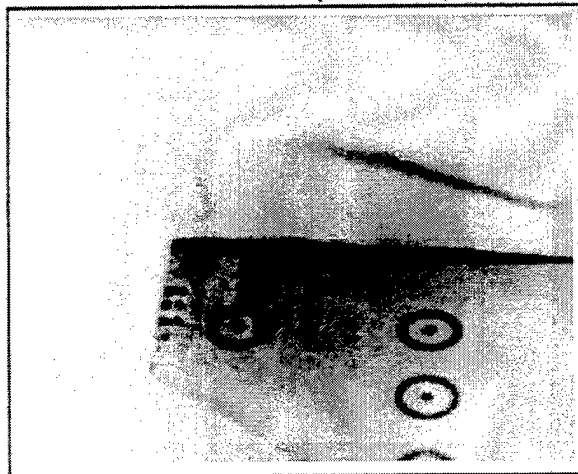
Sheet Pos. 11 (231-58-30)



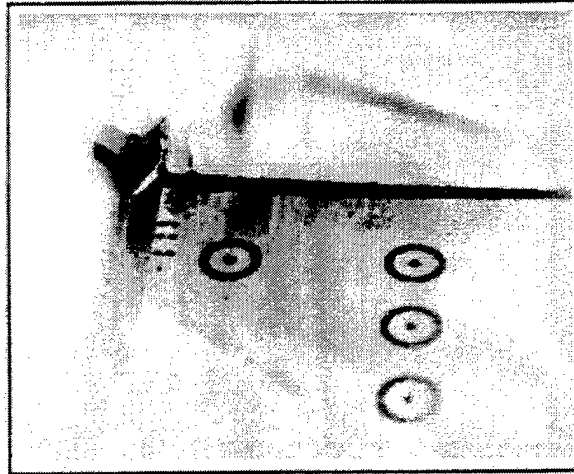
Sheet Pos. 12 (51-51-501)



Sheet Pos. 12 (246-72-227)



Sheet Pos. 13 (328-23-500)

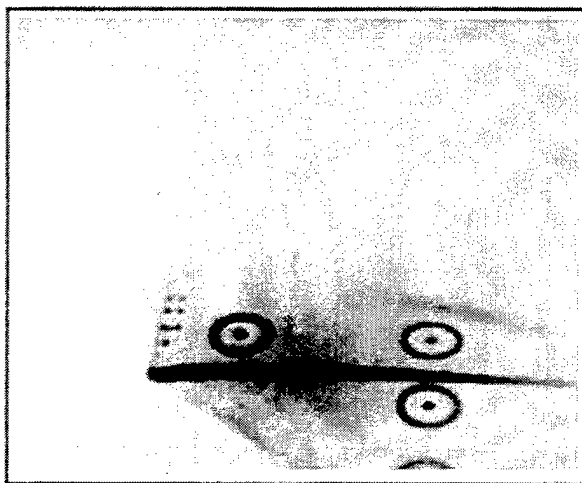


Sheet Pos. 13 (260-8-498)

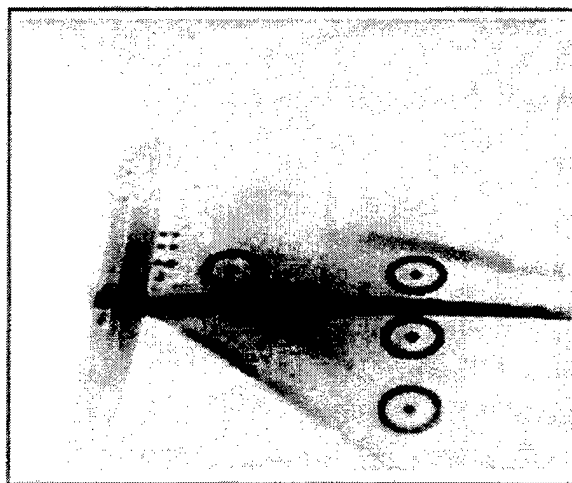
Clean Wing

Wing Tip Missile/Launcher

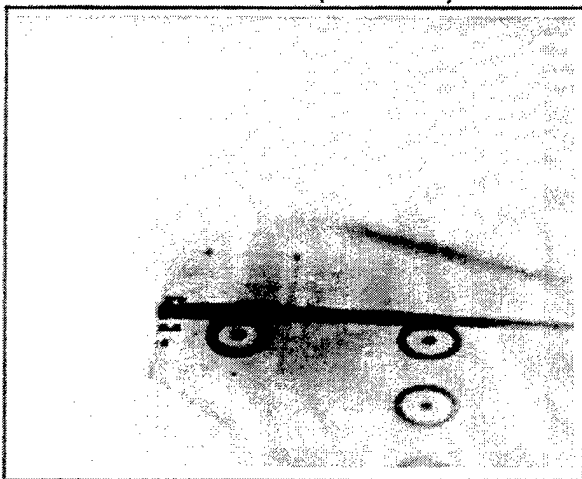
Figure 10.06 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 9.0$ deg



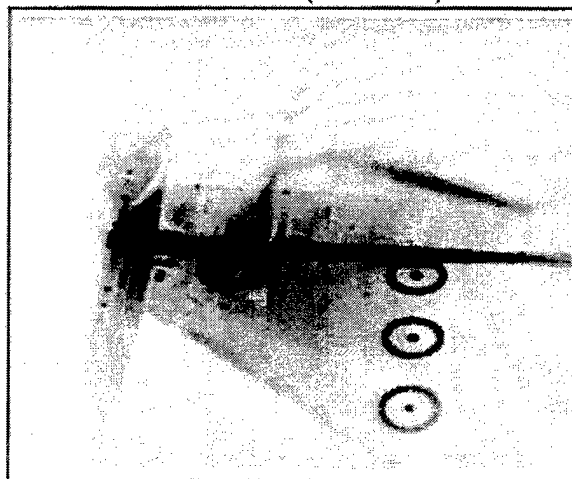
Sheet Pos. 11 (43-43-201)



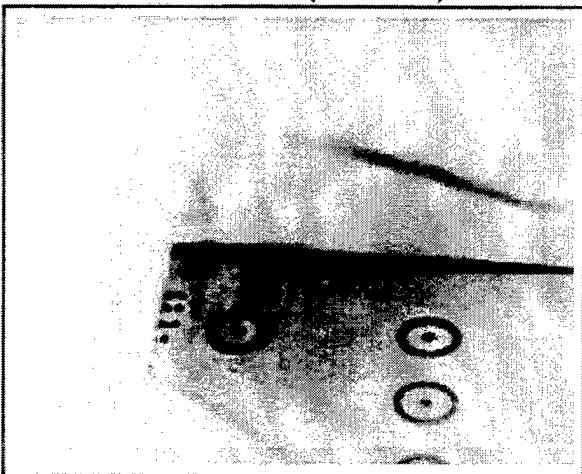
Sheet Pos. 11 (232-59-31)



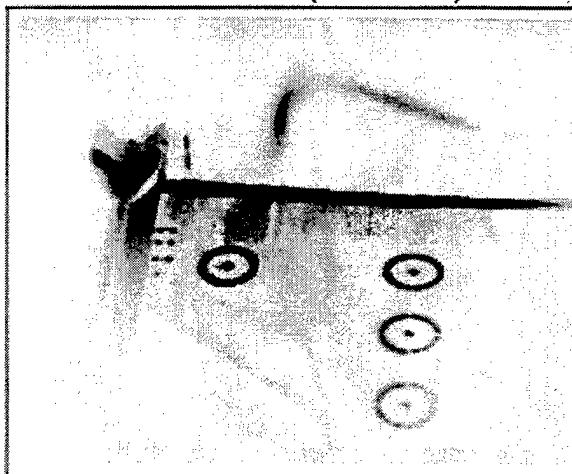
Sheet Pos. 12 (50-50-501)



Sheet Pos. 12 (247-73-237)



Sheet Pos. 13 (329-24-203)

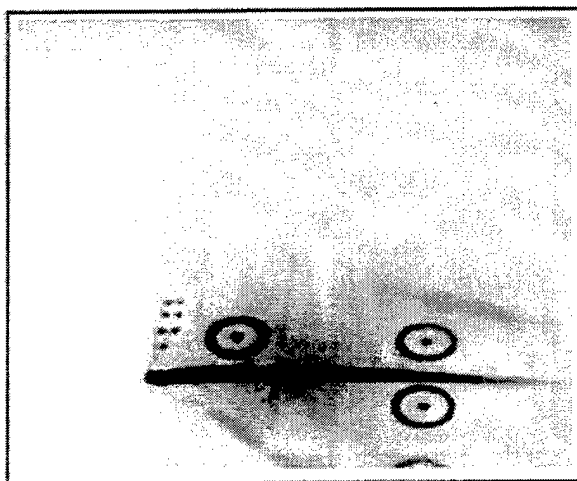


Sheet Pos. 13 (261-88-874)

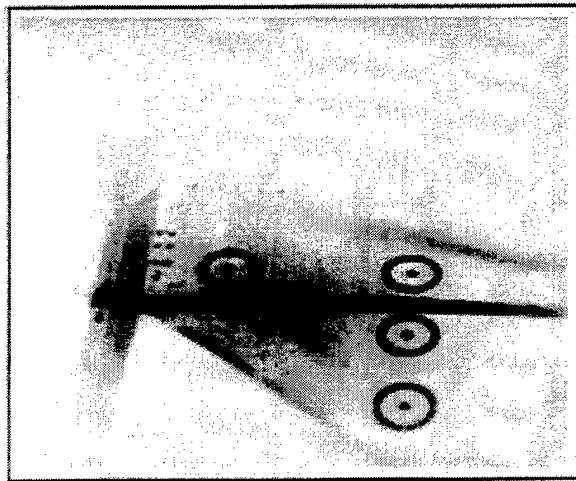
Clean Wing

Wing Tip Missile/Launcher

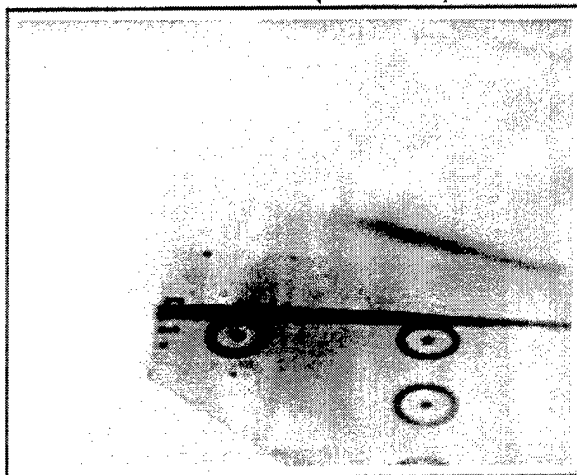
Figure 10.07 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 9.5$ deg



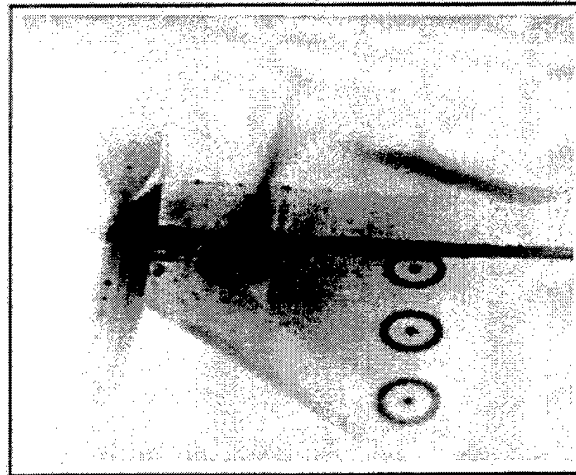
Sheet Pos. 11 (44-44-201)



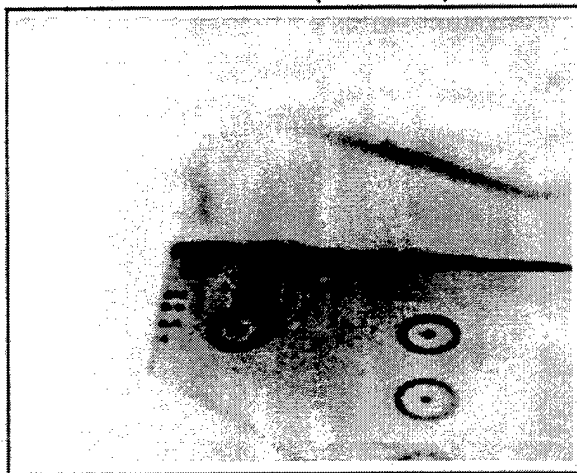
Sheet Pos. 11 (233-60-31)



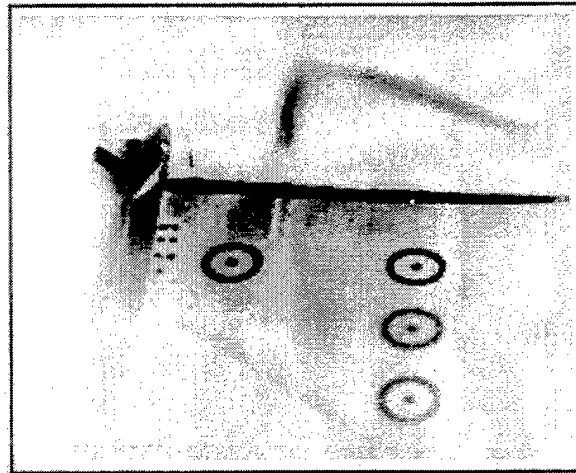
Sheet Pos. 12 (49-49-501)



Sheet Pos. 12 (249-74-415)



Sheet Pos. 13 (330-25-400)

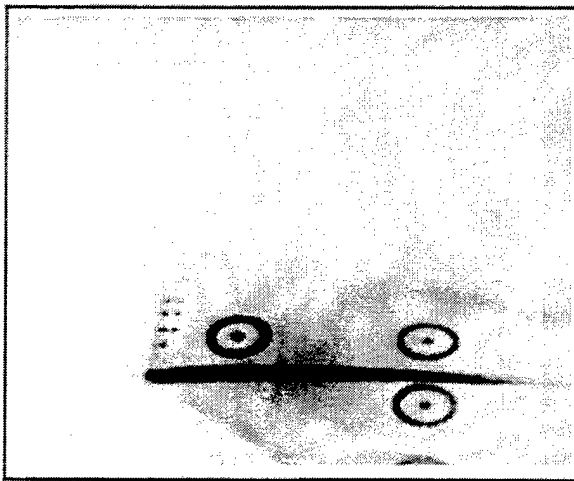


Sheet Pos. 13 (262-89-516)

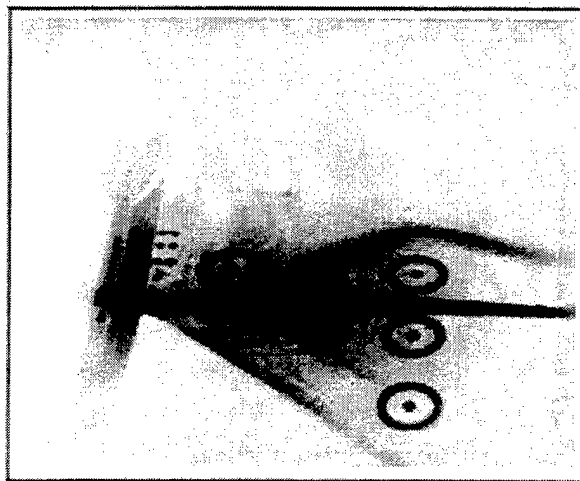
Clean Wing

Wing Tip Missile/Launcher

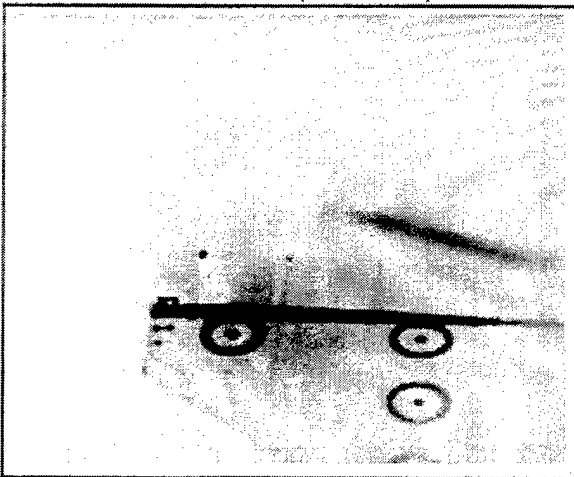
Figure 10.08 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 10.0$ deg



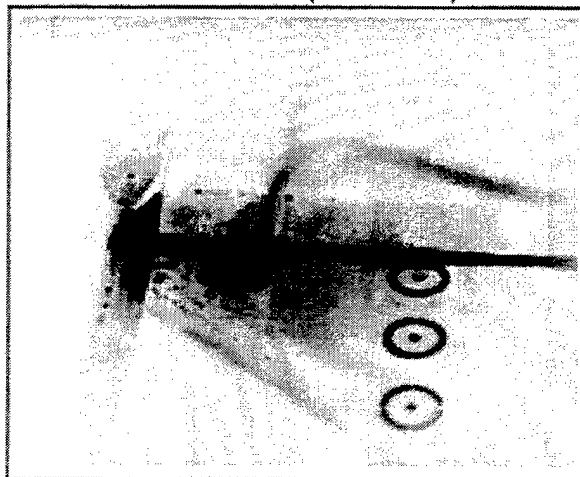
Sheet Pos. 11 (46-46-200)



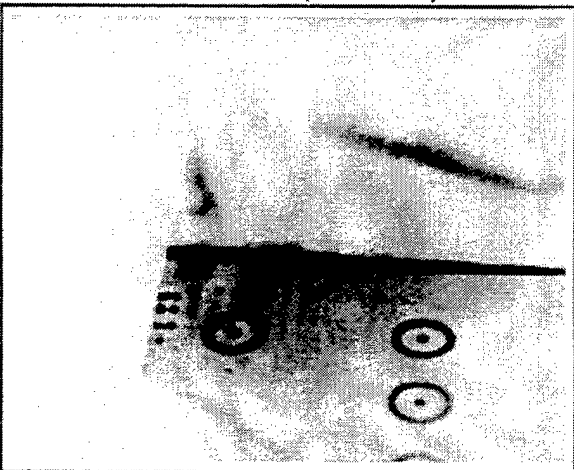
Sheet Pos. 11 (234-61-706)



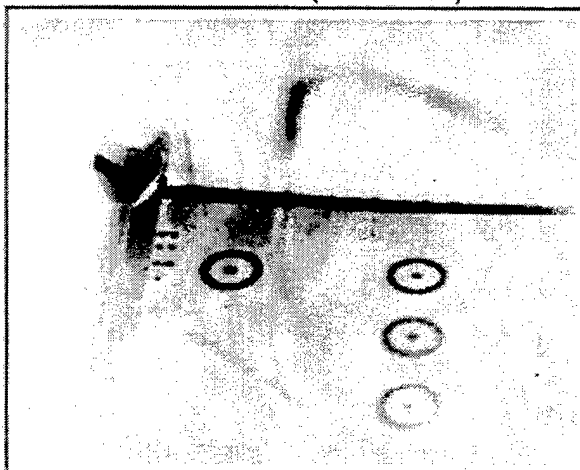
Sheet Pos. 12 (48-48-900)



Sheet Pos. 12 (238-65-260)



Sheet Pos. 13 (321-16-500)



Sheet Pos. 13 (253-80-360)

Clean Wing

Wing Tip Missile/Launcher

Figure 10.09 - High Speed Camera View of Spanwise Laser Light Sheet at $M = 0.90$, Comparison of Clean Wing and Tip Missile Configurations, $\alpha = 10.5$ deg

6.0 HIGH SPEED VIDEO LCO FLOW VISUALIZATION FOR THE WING WITH TIP LAUNCHER AT $M = 0.85$ AND 0.9

Individual frames from the high speed video data base for LCO-type conditions are presented in this section for two spanwise sheet positions, 11 and 12, as shown in Figure 11 below. The data base is similar to that described in the previous section. The data shown in this section in Figures 12.01 through 12.03 are also selected from the digital data base. They were selected to highlight the effect of Mach number on the development of LCO-type flows for the tip launcher configuration at $M = 0.85$ and 0.90 . (More work was done at $M = 0.85$ as a result of severe LCO encountered at $M = 0.9$ on the model. This was not the case for the tip missile configuration where LCO was present, but very mild).

Sheet Angle from
Vertical = 4.7°

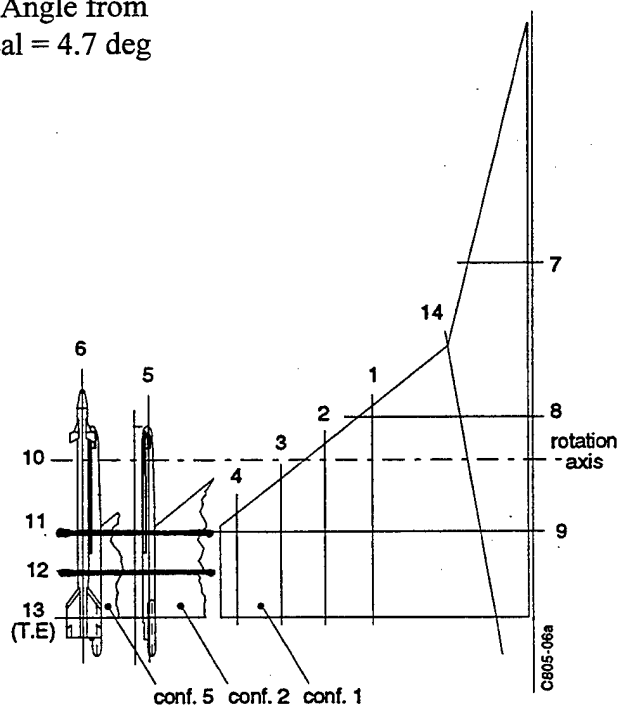
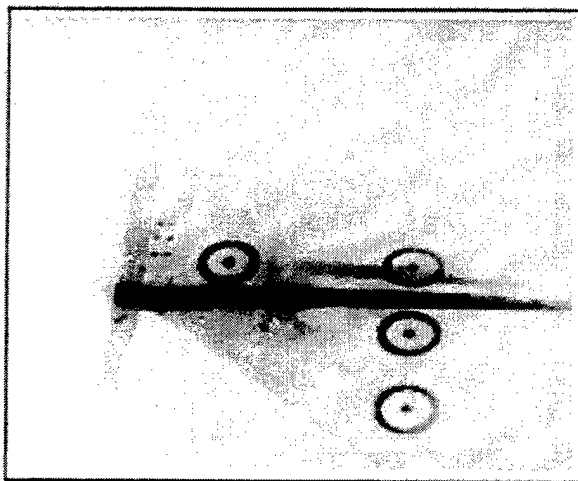
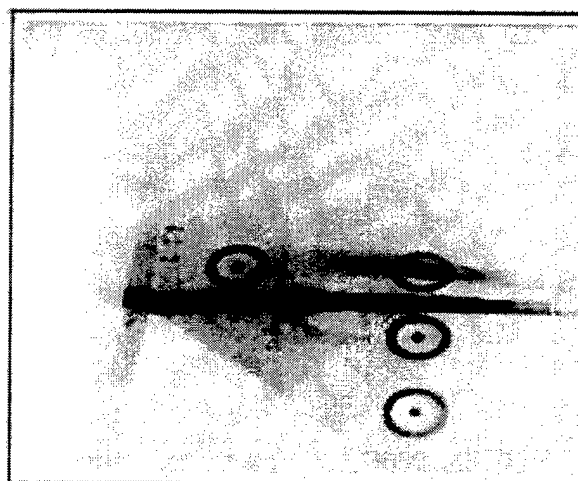


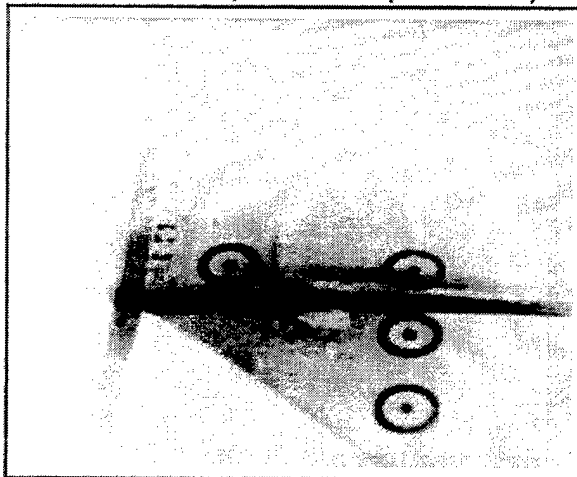
Figure 11 - Flow Visualization Locations for Figures 12, LCO Conditions, Wing With Tip Launcher, $M = 0.85$ and 0.9



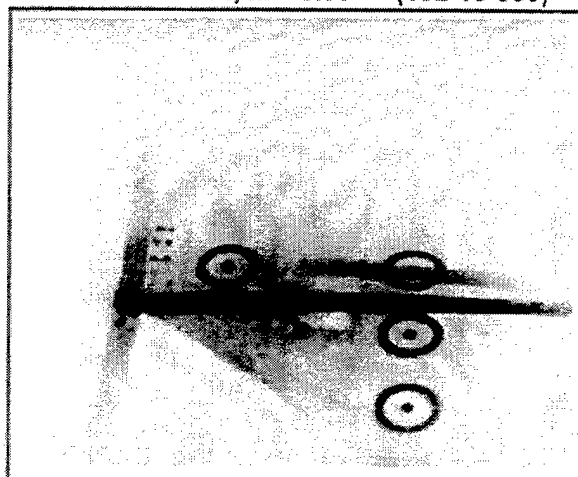
Sheet Pos. 11, $M = 0.90$ (161-14-336)



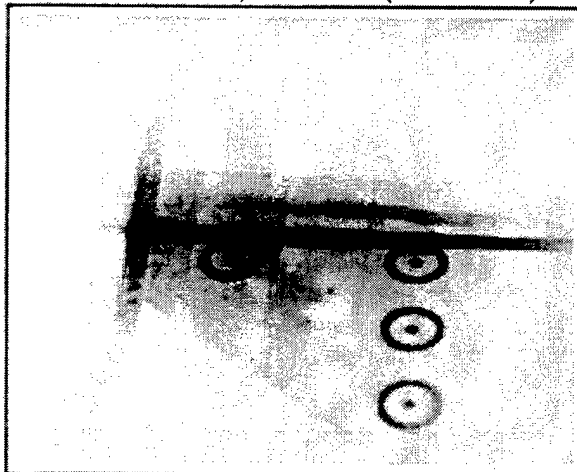
Sheet Pos. 11, $M = 0.90$ (162-15-950)



Sheet Pos. 11, $M = 0.85$ (172-25-700)

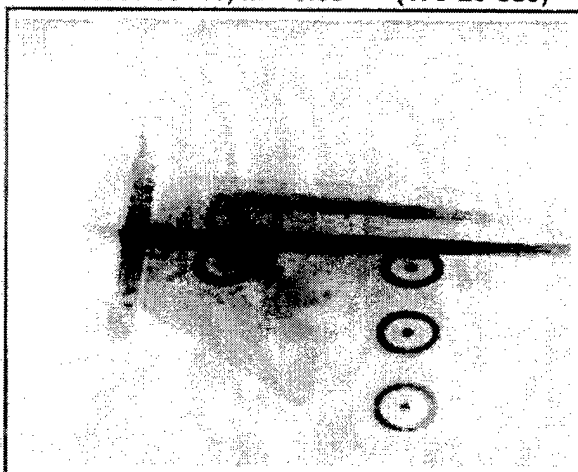


Sheet Pos. 11, $M = 0.85$ (173-26-350)



Sheet Pos. 12, $M = 0.85$ (102-35-563)

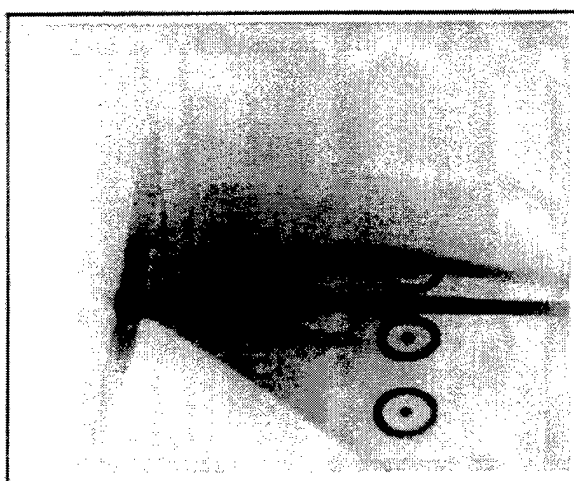
$\alpha = 6.5$



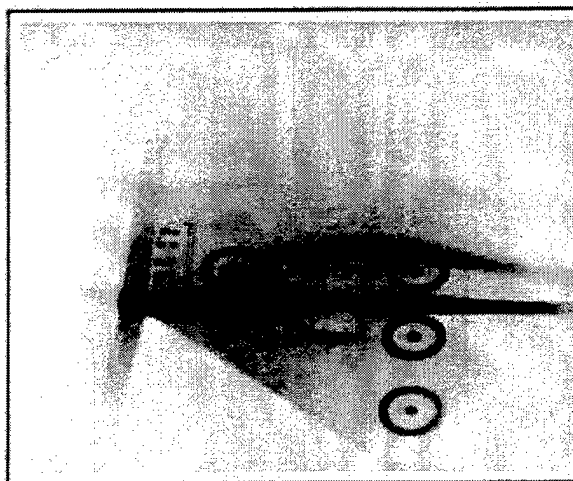
Sheet Pos. 12, $M = 0.85$ (183a-36-666)

$\alpha = 7.0$

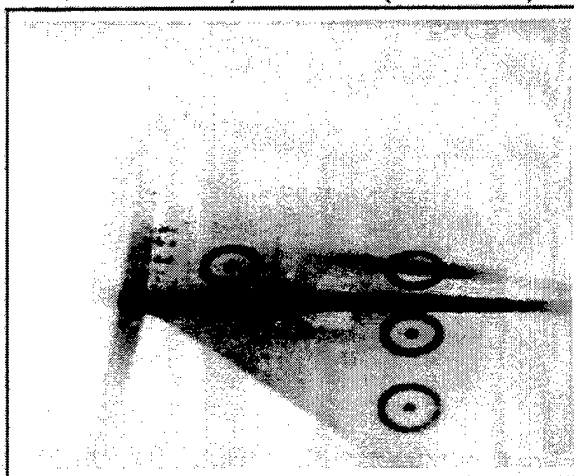
Figure 12.01 - High Speed Camera View of Spanwise Laser Light Sheet for the Tip Launcher Configuration at $M = 0.85$ and 0.90 , $\alpha = 6.5$ deg and $\alpha = 7.0$ deg



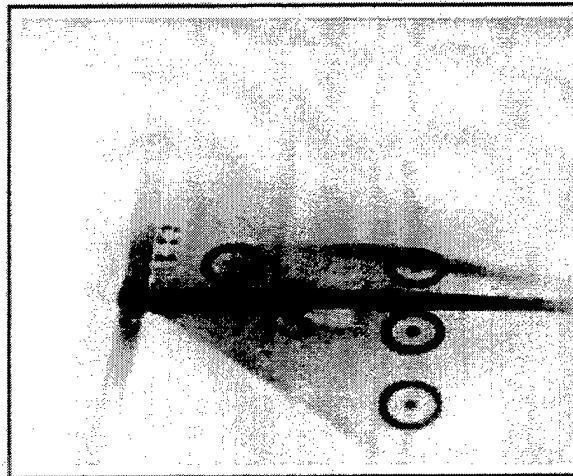
Sheet Pos. 11, $M = 0.90$ (164-18-585)



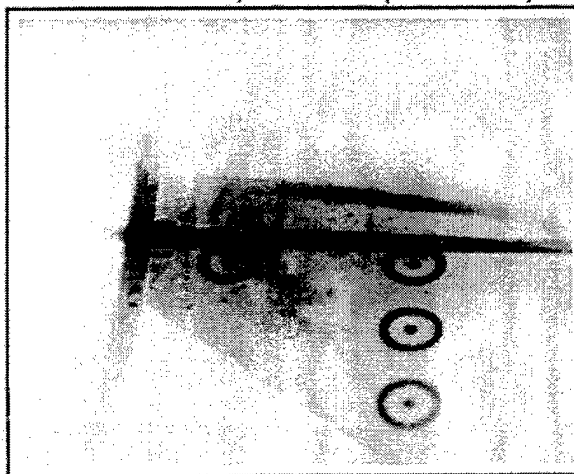
Sheet Pos. 11, $M = 0.90$ (165-19-220)



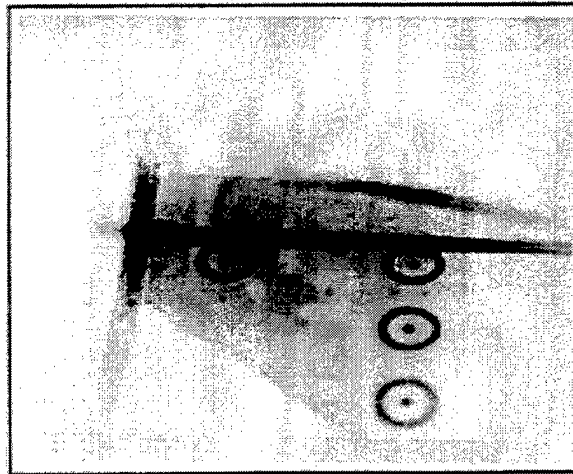
Sheet Pos. 11, $M = 0.85$ (174-27-301)



Sheet Pos. 11, $M = 0.85$ (175-28-540)



Sheet Pos. 12, $M = 0.85$ (184-37-956)

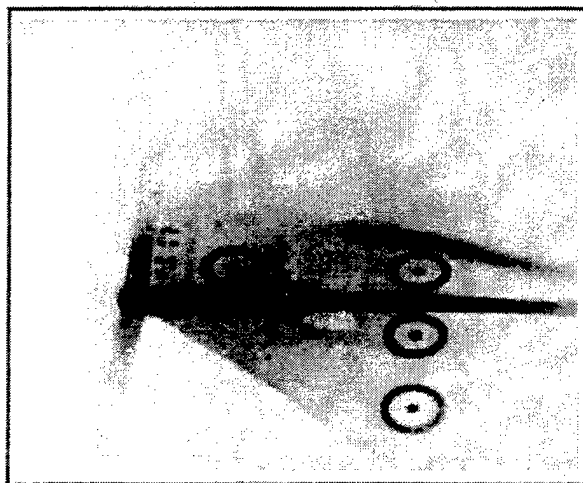


Sheet Pos. 12, $M = 0.85$ (185-38-29)

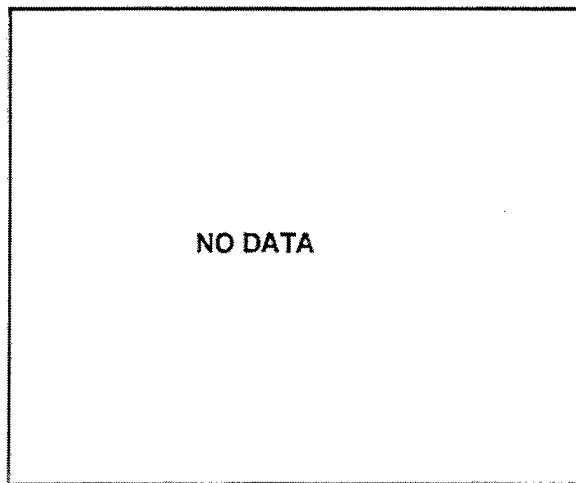
$\alpha = 7.5$

$\alpha = 8.0$

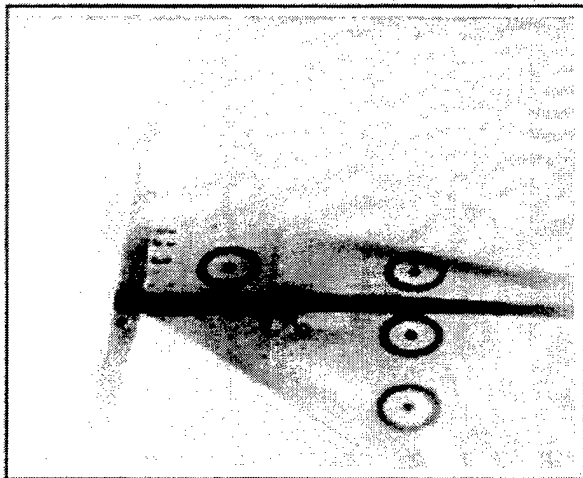
Figure 12.02 - High Speed Camera View of Spanwise Laser Light Sheet for the Tip Launcher Configuration at $M = 0.85$ and 0.90 , $\alpha = 7.5$ deg and $\alpha = 8.0$ deg



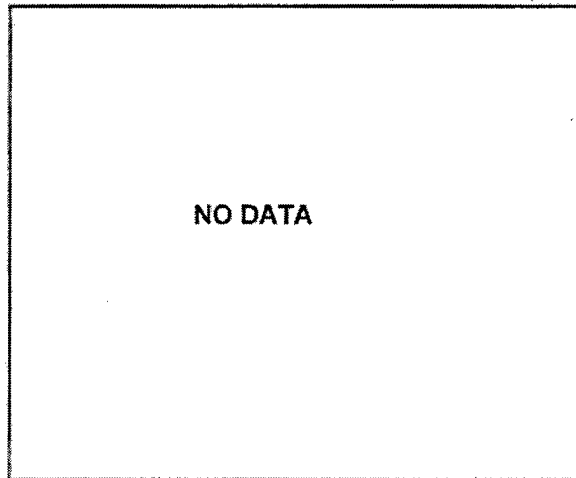
Sheet Pos. 11, M = 0.90 (166-20-620)



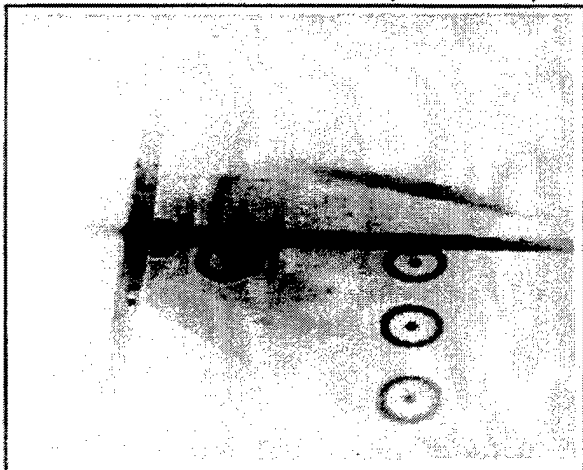
Sheet Pos. 11, M = 0.90 (xxx-xx-xxx)



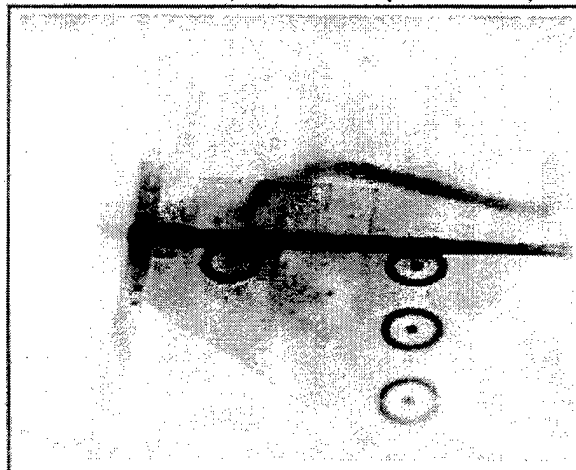
Sheet Pos. 11, M = 0.85 (176-29-780)



Sheet Pos. 11, M = 0.85 (xxx-xx-xxx)



Sheet Pos. 12, M = 0.85 (186-39-900)



Sheet Pos. 12, M = 0.85 (187-40-258)

$\alpha = 8.5$

$\alpha = 9.0$

Figure 12.03 - High Speed Camera View of Spanwise Laser Light Sheet for the Tip Launcher Configuration at M = 0.85 and 0.90, $\alpha = 8.5$ deg and $\alpha = 9.0$ deg

7.0 REFERENCES

1. Cunningham, A. M., Jr. and den Boer, R. G.: Overview of Unsteady Transonic Wind Tunnel Test on a Semispan Straked Delta Wing Oscillating in Pitch, WL-TR-94-3017 (Additional Wind Tunnel Reports WL - TR-94-3094, WL-TR-94-3095 and WL-TR-94-3096), August 1994
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